Anaesthesia in the prone position

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Key points

- The prone position is used for a variety of procedures ranging from short day-case procedures to prolonged major surgery.
- Changes in cardiovascular physiology depend on the specific prone position used; changes in respiratory physiology are generally advantageous.
- Injury can occur to all organ systems (including the eyes), due to direct or indirect pressure effects.
- For most cases, a securely fastened tracheal tube is the airway device of choice.
- In the event of a cardiac arrest, chest compressions and defibrillation can be commenced in the prone position.

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As surgical techniques evolve, the prone position is being used more frequently (e.g. laparoscopic-assisted oesophagectomy) to facilitate surgical access. It is also adopted to improve oxygenation in patients with acute respiratory distress syndrome (ARDS).

Nevertheless, the practice of prone positioning remains relatively unfamiliar to the majority of anaesthetists. This article will focus on prone positioning within the operating theatre. It will discuss the effects on physiology, the complications that occur, the practicalities of turning and positioning the patient, and the management of emergencies once prone.

Physiology

The changes to respiratory and cardiovascular physiology in the prone position have been extensively discussed elsewhere.[1] We present some of the key features.

Respiratory

In anaesthetized patients, the prone position confers a number of benefits in physiological parameters when compared with the supine position.

As long as abdominal movement is unimpeded, functional residual capacity and arterial partial pressure of oxygen are increased, yet chest wall and lung compliance remain unchanged.[1,2] These changes form part of the reason for the use of prone position in ventilated intensive care unit patients with severe refractory ARDS.

A gravitational theory to explain the improvements has been proposed and widely accepted. It suggests that pulmonary blood flow favours the dependent areas of the lung and better matching of ventilation and perfusion occurs, brought about by the following:

(i) gravity displacing the heart and smaller volumes of the lung being compressed.
(ii) improved diaphragmatic excursion, unhindered by the intra-abdominal contents.

However, single-photon emission computed tomography measurements in healthy ventilated patients have shown no change in the distribution of ventilation, but a more evenly distributed pulmonary blood flow, and improved matching of ventilation and perfusion.[3]

The gravitational theory has been challenged, and a model based on the branching architecture of the airways and pulmonary vessels has recently been proposed[4] that provides an alternative explanation for the improvements in matching of ventilation and perfusion seen in the prone position. This model, based on anatomy, offers some explanation why prone position can worsen respiratory parameters in some patients.

Cardiovascular

The decrease in cardiac output seen on turning prone is considered to be a result of reduced stroke volume. The resulting decrease in arterial pressure is, to some extent, countered by a compensatory sympathetic tachycardia and an increase in peripheral vascular resistance.

A decrease in pre-load is thought to be responsible for the reduced stroke volume that is seen. Many factors contribute to a decrease in pre-load and include:

(i) blood sequestration in dependent body parts;
(ii) caval compression;
(iii) increased intra-thoracic pressure with poor positioning and chest wall compression;
(iv) positive pressure ventilation and PEEP.

The type of prone position adopted can affect the changes observed in cardiovascular physiology. A study using transoesophageal ECHO (that excluded the obese patient or those with cardiovascular disease) measured cardiac index, stroke volume, and cardiac output in patients placed on the differing supports. The least effect on all cardiovascular parameters was seen with the Jackson table, whereas the cardiac index was decreased when prone on the Wilson table and the Andrews support (knee–chest position).[5]

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The jack-knife prone position has been shown to cause a decrease in cardiac index, a bradycardia, and raised mean arterial pressure that returned to supine values when the patients were placed in the Trendelenburg position.[6]

Variabilities in pulse pressure and stroke volume are greater in the prone position, compared with the supine position, and both can be used to predict whether the anaesthetized ventilated prone patient will respond to a fluid challenge. For practical purposes, patients with a pulse pressure variation of >14% are likely to respond to a fluid challenge.[7]

Cerebral blood flow

It is postulated that a rotated head position will reduce cerebral blood flow (CBF) and raise intracranial pressure by partial occlusion of the internal carotid and vertebral arteries, spinal vessels, and by compression of venous drainage. Vessel distortion can also occur from external pressure during positioning (e.g. by pillows), or from flexion or extension of the neck. Transcranial Doppler measurements of flow velocity (as a marker of CBF) across the middle cerebral artery demonstrated a reduction in CBF when the head was rotated to the side in healthy subjects ventilated with positive pressure.[8] The diameter of the internal jugular vein was also reduced indicating a reduction in cerebrovenous drainage.[8]

In patients where even modest reductions in CBF would be deleterious, for example, the elderly with vascular disease or those with raised intracranial pressure, the head and neck should be kept in the neutral position during turning and while in the prone position.

Renal function

A small study in non-anaesthetized healthy volunteers has shown a slight increase in urine output in the prone position but no difference in renal sodium excretion.[9]

Complications

Complications that occur from poor positioning cause morbidity, and in some cases mortality. Knowledge of the potential problems allows the practitioner to pay particular attention to areas at risk.

Pressure injuries

Pressure injuries are caused either directly by pressure on the affected tissue or indirectly by pressure to the vascular supply and drainage of the injured area (Table 1, Fig. 1).[1]

Table 1 Pressure injuries

Direct pressure injuries	Indirect pressure injuries
Skin necrosis	Macroglossia and orpharyngeal Swelling
Contact dermatitis	Mediastinal compression
Tracheal compression	Visceral ischaemia—liver, pancreas
Salivary gland swelling	Avascular necrosis of femoral head
Breast injury	Peripheral vessel occlusion
Injury to the genitalia	Limb compartment syndrome and rhabdomyolysis
Compression of the pinna	
Compression of the femoral neurovascular bundle	

Ophthalmic complications

Ophthalmic complications range from corneal abrasions to devastating postoperative visual loss. Visual loss has an incidence of 1:60 000–1:125 000 but is more common in spinal surgery (1:30 000).[10]

There are two mechanisms, with differing aetiology. Direct pressure on the eye can lead to central retinal artery occlusion, whereas ischaemic optic neuropathy can occur without any pressure on the globe or orbit.[10]

Of 83 cases of postoperative visual loss reviewed in America,[11] 16 occurred in patients whose face and eyes were free from pressure, with the head in pins and supported by the Mayfield clamp. Lengthy surgery (over 6 h) or blood loss >1000 ml was present in 96% of the reported cases. Risk factors identified included patients with atherosclerosis, diabetes, hypertension, and male gender. More than half of the patients had bilateral visual loss; less than half had recovery of some vision (light/dark perception).

There was no association with pre-existing glaucoma, arterial pressure management intraoperatively (but deliberate hypotensive anaesthesia remains under suspicion), anaemia (*per se*), hypothermia, type of prone support used, or type of anaesthetic administered.[11]

The exact aetiology of ischaemic optic neuropathy has not been elucidated, but may be due to reduced venous drainage and increased interstitial fluid around the optic nerve causing a 'compartment syndrome'.[11]

Peripheral nervous system

Injuries to the peripheral nervous system are one of the most common complications[12] and all superficial peripheral nerves should be considered at risk. It is widely believed that poor positioning and compression or stretch of the nerve within its narrow boney canal (ulnar nerve at the elbow) or from external compression (common peroneal nerve by straps/pads below the knee) is responsible for the development of a neuropathy. However, a large study found ulnar neuropathy in the absence of general anaesthesia, long procedures, or poor padding—suggesting other factors play a part.[13] Nevertheless, careful positioning can still reduce stretch and pressure injury.[12]

Cases of peripheral neuropathy do not usually present in the recovery room. Symptoms often occur only after 24 h, with over 90% of cases presenting within 7 days; the symptoms can be sensory (47%) or mixed motor/sensory. About 53% of patients will recover within a year, those with sensory loss are more likely to make a full recovery compared with those with mixed motor/sensory deficit, but one-quarter will suffer persistent pain.[13]

Risk factors that have been identified are being male (70%), a prolonged hospital stay, extremes of body habitus, and diabetes. Advanced age increases the risk of motor neuropathy.

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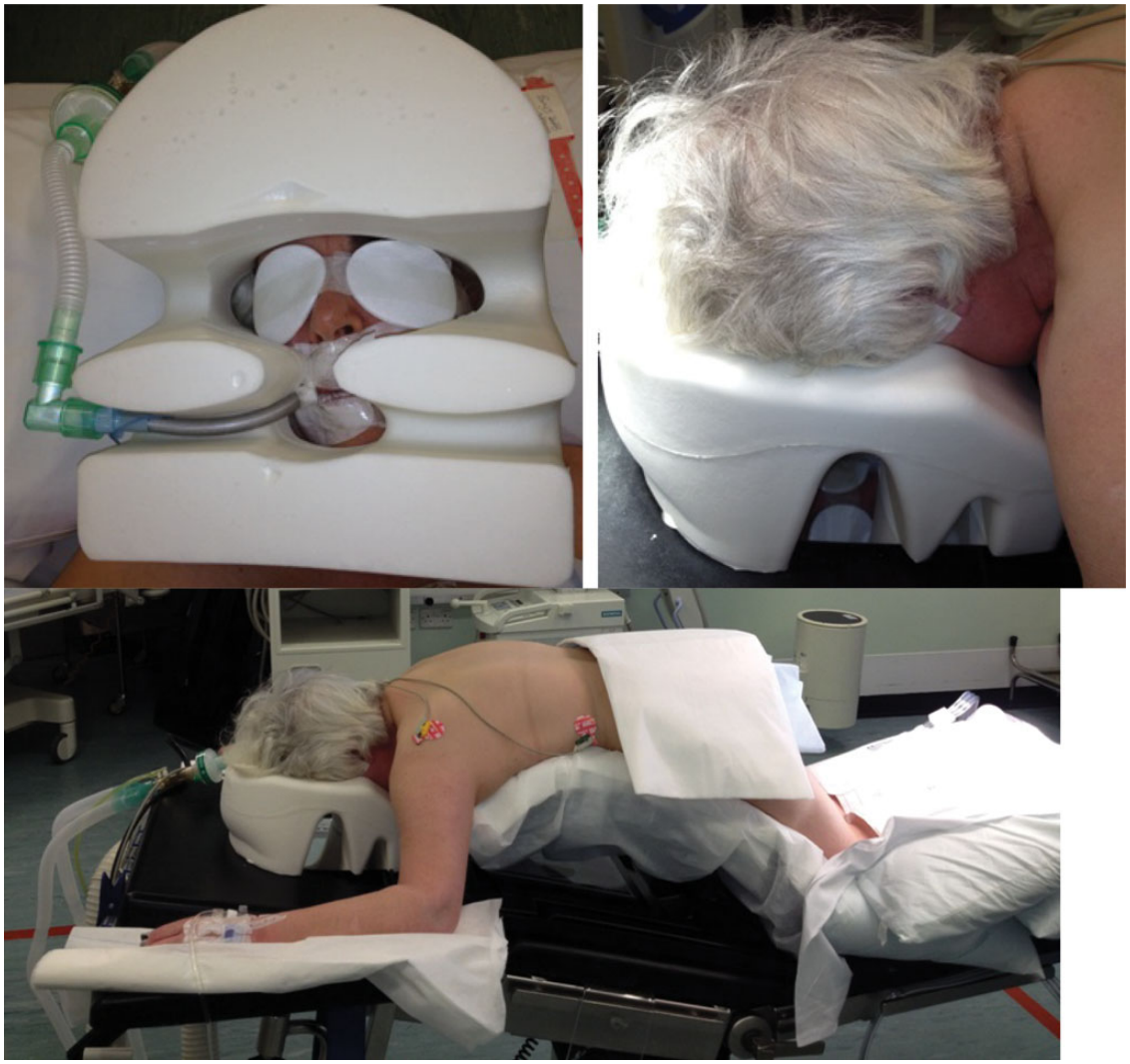

Fig 1 Patient A positioned on Wilson frame with DisposaView™ headrest. The headrest is applied with the patient still supine. Note the final position of the neck. The mirror permits easy confirmation of face support without pressure to the orbit or globe. All pressure areas are padded and protected.

Placing the arms by the side provides the greatest protection for the ulnar nerve and brachial plexus. If the arms are to be abducted, they should have no greater than a 90° bend at the elbow or shoulder. Direct pressure in the axilla should be avoided to protect nerves and vessels, and the elbows should be well padded. The rotator cuff can also be damaged during positioning of the arms.

In the lower limbs, the lateral cutaneous nerve of the thigh is at risk from compression in the prone position.

Central nervous system

Some complications to the central nervous system have been discussed earlier. While rotation of the head has been considered, it is also important to take care not to over-extend or flex the cervical spine. Those patients with an unstable spine should be log rolled and it is our practice (once the airway has been secured) to transfer care of the head and neck during positioning to the surgeon in this group.

Cases of hypotension and arterial hypoperfusion leading to ischaemic stroke of the brain and spinal cord have been reported.[1]

Practicalities

Six members of staff are needed to position a patient prone: one person (usually the anaesthetist, except in cases of unstable spine injury) at the head, one moving the feet, and two either side of the patient. Additional members of staff may be required for obese patients or patients with unstable spines requiring 'log-rolling'. Alternatively, specialized equipment such as the Jackson table can be used to turn the patient, see the in-line video that can be viewed online from Figure 2. It is our practice to disconnect monitoring, infusions, and the breathing system while turning the patient to

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decrease the risk of accidentally dislodging lines or the tracheal tube (TT). As soon as the patient is prone all lines, monitoring and the breathing circuit are reconnected.

In practice, the table supports used (e.g. the Wilson frame, especially in obese patients) do not allow completely free movement of the abdomen and chest wall and thus turning the patient prone will lead to reduced dynamic lung compliance and increased peak airway pressure. It is worth making a note of the supine airway pressures, as in our practice, sustained or significant increases ($>$5 cm H_2O) once prone position trigger a check for causes such as bronchospasm or inadvertent endobronchial intubation.

The advantages and disadvantages of commonly used operating tables and head supports are summarized in Table 2. For photographs of commonly used equipment, see Figure 2A and B.

Airway management

A securely fastened reinforced cuffed TT is considered the airway of choice for patients in the prone position and is the authors' preference.

However, there is a small yet increasing trend towards the use of a supraglottic airway device. Articles reporting successful use of these devices for elective surgery, and as an airway rescue

Table 2 Commonly used body supports and head supports. See Figures 2A body supports and Figure 2B head rests, along with the in-line video showing the building and turning of the Jackson sandwich that can be viewed online from Figure 2, and Supplementary Allen Table S1.

Body support	Use	Advantages	Disadvantages
Pillows	Quick cases	Quick to set up	Only limited chest support and difficult to ensure a free abdomen as they are compressible The pillows can move during the procedure or positioning
Chest roll		Easy to ensure a free abdomen	Direct and indirect pressure injury Has been associated with cases of hepatic failure when poorly positioned
Pelvic roll	To elevate the anus and rectum		Direct and indirect pressure injury
Thoracic support/ Montreal mattress	Cervical and thoracic spinal surgery Oesophageal surgery Urology	Different sizes. Easy to store and place on the table. Allows free abdominal movement. Easy to place arms by the sides or flexed and abducted	Direct pressure to groin if incorrectly sized
Allen table/Jackson table	Spinal surgery, especially with instrumentation requiring radiology access	Abdomen and chest free. Some have specific arm supports and a mirror to permit easy view of the face and TT. Excellent for the use of C-arm image intensifier. Permit wide range of rotation of the patient. Movable supports so the frame can be adjusted to the individual patient. Minimal change in cardiovascular physiology. The table can be used to turn the patient prone	Large piece of equipment Patient's head distant from the anaesthetist and difficult to access the airway Cumbersome control mechanism for height and rotation (Allen) Dual control to operate both theatre and operating tables. The torso is on the operating table, the legs on the theatre table (Allen)
Wilson frame/reverse saddle support	Lumbar spinal surgery	Permits loss of lumbar lordosis Pressure distributed across patients sides so the pelvis and chest supported while the abdomen remains free	Can only adjust width of supports so may be too long for some patients. Difficult to position arms by the sides
'Cambridge Frame'/ Relton–Hall frame	Scoliosis surgery	Can be adjusted for each patient Allows good X-ray access	Patient rests on four pressure points only, can cause skin necrosis in prolonged surgery
Andrew's frame (knee/chest position)	Occipital, cervical, lumbar, perineal/perianal surgery	Permits loss of lumbar lordosis. Excellent surgical access to spine and perineal structures.	Decreases in cardiac index and stroke volume due to venous pooling in the legs. Pressure areas on knees and risk of lower limb nerve injury. Requires chest roll, and chest can be unstable. Requires multiple people to position
Head support			
Mayfield clamp and pins	Craniotomies, cervical spinal surgery	No direct pressure on eyes (damage can still occur) Easy to access TT	Risk of scalp lacerations No TT support
Preformed foam, e.g. Disposaview™	All cases, newer pre-formed foam masks are marketed as being suitable for up to 8 h use	Easy view of the eyes Preformed and easy to check positioning	One size does not always fit all Pressure areas if used in prolonged surgery Difficult to access the TT Expensive and not reusable Too low in profile for double-lumen tube
Gel support	All cases	Different types with different height profiles. The higher profile support permits the use of the double-lumen tube Reusable	Shape is distortable so head can move. Difficult to check for pressure on eyes
Horseshoe	Quick procedures	Usually easily available	Can change position when the patient moved. If used as a table extension, it ensures the face is free and easy access to airway and TT
Gel ring	Quick procedures	Easily available	Must have head turned, risk of vessel, nerve, or bony injury
Pillows	Quick procedures	Easily available	Must have head turned, risk of vessel, nerve, or bony injury

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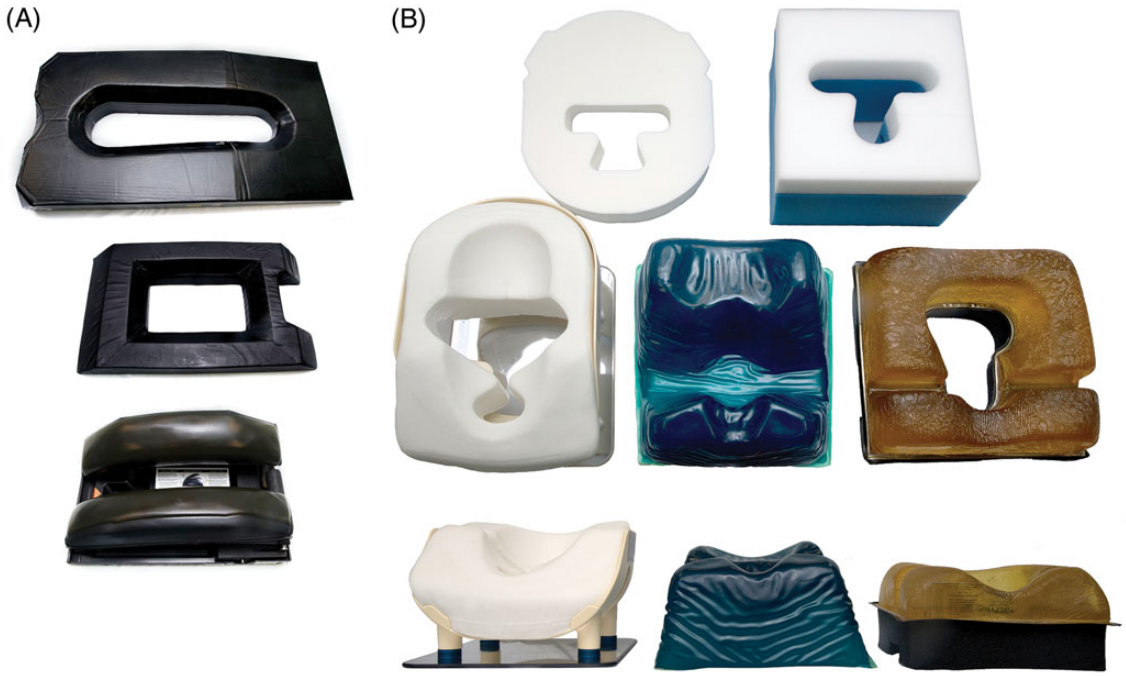

Fig 2 (A) Commonly used 'table top' prone body supports. Top, Montreal mattress; middle, thoracic support; bottom, Wilson frame. (B) Head rests for the prone position. The choice of rest chosen will depend in part on the height profile of the head rest and the body position of the patient. The yellow support has a lower height profile and can be used when the patient is positioned on pillows or a Montreal mattress; the turquoise support has a higher profile and is suitable when the patient is supported on the Wilson frame. Some head rests come as part of the prone table, for example, the white supports on the left of the image are compatible with the Jackson table; the lower support has a mirror to allow easy confirmation that the orbit is free from pressure. If reading the PDF online, please click on the image to view the video. The video demonstrates how to build the 'sandwich' and use the turning function of the Jackson table.

technique, are becoming more frequent. The LMA Supreme™ and the Proseal LMA™ were studied in audits of more than 200 patients.[14] Anaesthesia was induced in the prone position with the head rotated to one side. It was claimed the drainage tube allowed easier detection of displacement during positive pressure ventilation and the shape of the LMA Supreme™ made accidental rotational displacement less likely. In the study involving the LMA Supreme™, four cases of regurgitation with no clinical signs of aspiration were reported, but the number of cases was small.

The DAS guidelines for difficult extubation do not address extubation after prone surgery. In our institution, we perform a 'leak test' after prolonged procedures and for cases performed in the prone Trendelenburg position before extubation.

Management of emergencies

Accidental extubation

Anticipation and planning prepares the anaesthetist for timely management of accidental extubation (AE) in the prone position.

The security and patency of the airway must be checked immediately after turning the patient, and the bed not permitted to leave theatre until the correct TT position has been confirmed. If it has become dislodged, the patient can be turned supine on to the bed and reintubated without delay. The TT should be rechecked after any re-positioning of the patient or their head. Once the patient is positioned, and the head and tube supported AE is unlikely. If the head is secured in pins and the Mayfield clamp, AE may still occur during surgery if the TT is 'free hanging'.

Case reports have highlighted the use of supraglottic devices for airway rescue. Placement of the LMA provided a patent airway in the majority of cases at first attempt (87.5%), and 100% at second attempt.[15] The decision to continue surgery with the LMA or whether to re-secure a TT has to be made on a case-by-case basis, taking account of the nature and duration of surgery. The LMA can be used as a conduit for the passage of a fibreoptic scope and TT in the prone position.

An alternative is the use of fibreoptic re-intubation in the prone position to secure the airway. The anatomy for oral intubation is favourable—the tongue falls forward, negating the need for jaw thrust or 'tongue pull'. This is only a solution if the fibreoptic scope is immediately available and the face is easily accessible, for example, when the head is secured in pins and the Mayfield clamp.

Cardiac arrest

Cardiac arrest in the prone position is a rare event. The UK resuscitation council is preparing specific guidance for the management of

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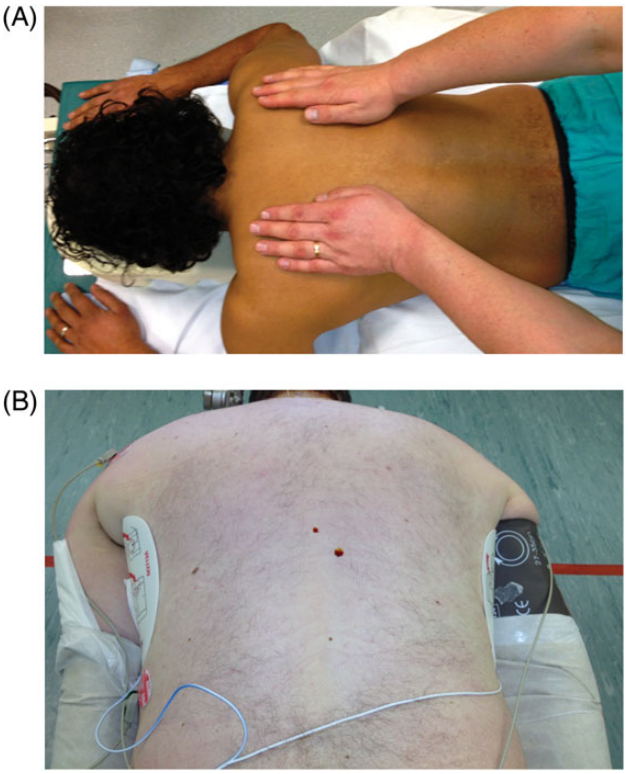

Fig 3 (A) Hand position for chest compressions in the prone position assuming midline surgery. Note the hands should be placed over both scapulae. (B) Defibrillator pads are demonstrated in the postero-lateral position.

cardiac arrest in neurosurgical patients including those in the prone position, and we await its publication. In the meantime, case reports have described successful resuscitation and defibrillation in the prone position. This has allowed immediate commencement of cardiopulmonary resuscitation while preparing to turn supine. Chest compressions have been performed using several methods including placing a hand over each scapula (Fig. 3A), compressions over the thoracic spine with or without counter-pressure on the sternum, or open cardiac compressions if surgery already involves a thoracotomy.[16]

Successful defibrillation has been described with the following pad positions:

(i) antero-posterior,
(ii) right axilla and cardiac apex,
(iii) postero-lateral (Fig. 3B).[16]

If the anaesthetist considers the patient to be at risk for intraoperative cardiac arrest (or in potential need of pacing/synchronized DC cardioversion), defibrillation pads should be placed before turning prone, and checked before commencing surgery. High-risk patients would be identified in the same way as for a patient undergoing surgery in the supine position. The resuscitation council considers it safe for the gloved surgeon to support the head to protect the cervical spine from movement injury when a biphasic shock is applied to the patient.

Conclusion

An understanding of physiology, the practicalities, and complications for prone positioning can make this position less stressful for the anaesthetist who practices it infrequently. Departments developing a prone service can include the correct equipment and staffing levels at the planning stages. In addition, risks can be fully explained to the patient.

Supplementary material

Supplementary material is available at *Continuing Education in Anaesthesia, Critical Care & Pain* online.

Declaration of interest

None declared.

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Please see multiple choice questions 29–32.

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BJA

Anaesthesia in the prone position

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Prone positioning of patients during anaesthesia is required to provide operative access for a wide variety of surgical procedures. It is associated with predictable changes in physiology but also with a number of complications, and safe use of the prone position requires an understanding of both issues. We have reviewed the development of the prone position and its variants and the physiological changes which occur on prone positioning. The complications associated with this position and the published techniques for various practical procedures in this position will be discussed. The aim of this review is to identify the risks associated with prone positioning and how these risks may be anticipated and minimized.

Br J Anaesth 2008; **100**: 165–83

Keywords: complications, neuropathy; complications, respiratory; position, effects; position, prone; surgery, spinal

Historical development

The prone position has been described, used, and developed as a result of the requirement for surgical access. However, pioneers of spinal surgery in the 1930s and 1940s were hampered because no effort was made to avoid abdominal compression when positioning the patient, somewhat surprisingly given that the valveless nature of the venous system was well understood at the time. Increased intra-abdominal pressure forced blood from the inferior vena cava (IVC) into the extradural venous plexus, resulting in increased bleeding and a poor surgical field. The position adopted enhanced the natural anterior curvature of the lumbar spine, making surgical access even more difficult. In addition, the aorta, vena cava, and small bowel were forced against the lumbar spine where they were at risk of injury during surgery. Surgical access was also hindered by the limitations of contemporary anaesthetic techniques—most operations were performed with the patient breathing spontaneously, and increased muscle tone served to increase bleeding and impair the surgical field even more. Local anaesthesia was only partially successful, having a limited effect on inflamed spinal nerve roots.

In 1949, Ecker[47] provided the first description of a new position which attempted to overcome some of the adverse effects of increased intra-abdominal pressure in the prone position. Since then, many positions and devices have been described to refine this, all under the blanket term 'prone position', but with subtle differences (Table 1) and varying advantages and disadvantages.

Physiological changes in the prone position

Cardiovascular

Decreased cardiac index

When moving a patient into the prone position, an almost universal finding is a decrease in cardiac index (CI). In 16 patients[16] with cardiopulmonary disease during surgery in the prone position, the most marked finding was an average decrease in CI of 24% which reflected a decrease in stroke volume, with little change in heart rate. Mean arterial pressure (MAP) was maintained by increased systemic vascular resistance (SVR), and pulmonary vascular resistance (PVR) also increased in the majority of patients. No changes were noted in mean right atrial or pulmonary artery pressures (PAP). Interestingly, these alterations in cardiac function were only noted because cardiac output was measured and central venous and intra-arterial pressure measurements would not have identified this. This decrease in CI in the prone position has been confirmed elsewhere,[70] although in contrast, one study using transoesophageal echocardiography in patients undergoing lumbar laminectomy[199] showed that although central venous pressure (CVP) increased slightly when patients were moved from supine to prone, CI did not change.

However, it appears that the specific prone position used may influence these findings. A study of 21 patients undergoing lumbar surgery with direct PAP or IVC pressure monitoring[226] demonstrated that the flat prone position did not interfere with circulatory function but that positioning

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Table 1 Historical variations on the prone position. *Modern versions include the Wilson Frame, whose two curved full-length pads are adjustable laterally to optimize positioning, and the Cloward Surgical Saddle (US Patent No. 4398707). †The 'Buie' position[175] is similar to the Georgia prone, but involves a head-down tilt and is useful for ano-rectal surgery. A hypobaric spinal block is possible. ‡The Ray Frame[155] assumes a similar position but with more even weight distribution on the knees, and the arms adducted across the chest. ¶The Seated Prone position as described by Tarlov[190] is also referred to as the 'Knee–Chest' position. A similar position is adopted using the Andrews Table and the Codman Frame. §Other authors describing similar positions to Tarlov include Hastings,[69] Laurin and colleagues,[101] and Dinmore.[42] ||The Hastings Frame is also known as the 'Toronto' or 'Canadian' Frame in some publications. Similar devices include the Heffington Frame.[186] #The 'Concorde' position[94] is identical except that the head is flexed on the neck and tilted to the right. This allows good access to the pineal region without the disadvantages of the sitting position

Variation	Description	Advantages	Disadvantages
'Kneeling' prone[47]	Thighs and knees flexed and splayed	Reduced intra-abdominal pressure	Risk of crush injury to thigh and calf muscles
	Chest supported in sling	Flexion of spine	
	Arms crossed in front of face	Reduced tension on nerve roots	
'Mohammedan Prayer'[111]	As for 'Kneeling', but: chest supported with pillows	Reduced intra-abdominal pressure	Risk of crush injury as above
	Arms abducted at shoulder above head	Flexion of spine	Increased tension in paraspinal muscles
	Head-up tilt		Manual handling issues
Moore and Edmunds Frame[129]	Patient suspended between longitudinal bars of curved frame	Reduced intra-abdominal pressure	Pressure injury
		Portable	
		Cheap	
Overholt position[49]	Crest of ilium supported by edge of table. Adjustable pad under upper third of sternum. Head in headrest	Free chest expansion allows spontaneous respiration during thoracic surgery	
Mackay Frame[117]	Two longitudinal curved bolsters	Adjustable curvature for any degree of flexion/extension	
	Patient supported on iliac crests and mid-clavicles	Cheap and robust	
	Arms extended above head*	Reduced intra-abdominal pressure	
'Prone Jack Knife'[191]	Pelvis supported (weight borne on anterior pelvis and sternum)	Much reduced intra-abdominal pressure	Does not undo lumbar lordosis (poor surgical access to spine)
	Knees semi-flexed		Risk of femoral vessel injury
	Thighs flexed to 45°		
	Arms abducted at shoulders		
'Georgia Prone'[†,‡ 177]	Kneeling on shelf, hips flexed at 90°; weight borne on knees	Patient comfort (derived from experiments on awake subjects)	Manual handling issues
	Pelvis supported under iliac crests	Good surgical access (thigh flexion flattens lumbar spine)	All weight borne by knees
	Pillows under chest		Increased CVP
	Arms abducted above head		Tight paraspinal muscles can limit lateral surgical access
	Head turned to side		
Relton and Hall Frame[157]	Four individually adjustable supports in two V-shaped pairs tilting inwards at 45°	Reduced intra-abdominal pressure	Increases lumbar lordosis (unsuitable for disc surgery)
	Supports lateral thoracic cage and antero-lateral pelvis	Tends to correct scoliosis	
		Adjustable for any body habitus and degree of scoliosis	
		Very stable	
		Can be modified to allow skeletal traction[131]	
'Seated Prone'[¶,§ 190]	Weight supported on ischial tuberosities	Very low venous pressures[32]	Theoretical risk of venous air embolus (because of low venous pressures)
	45° head-up tilt making back horizontal	Weight borne on ischii, not knees	Unstable position
	Chest padded	Reduced risk of crush injury and deep venous thrombosis	Tight paraspinal muscles can limit lateral surgical access
	Head rotated		
	Arms abducted above head		
'Tuck' position[214]	Very similar to 'Prayer' position	Low venous pressures	Risk of crush injury and deep venous thrombosis
	Hips flexed >90°	Spinal flexion improves surgical access	Tight paraspinal muscles can limit lateral surgical access
	Head-down tilt	Fewer manual handling problems	
Hastings Frame[||69]	As for 'Seated prone'	More stable than 'Seated prone'	Venous pooling in legs
	Wooden frame with adjustable seat	Degree of spinal flexion variable	

Continued

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Table 1 (*Continued*)

Variation	Description	Advantages	Disadvantages
Smith Frame[176]	Two curved supports under iliac crests Pile of folded sheets under chest Neck flexed and rotated	Free abdomen, adjustable for any degree of obesity	Risk of pressure necrosis over iliac crests Risk of lateral femoral cutaneous nerve palsy
'Sea lion' position[#78]	Back hyperextended on the pelvis; head up and extended on the neck	Good access to posterior cerebral structures with low venous pressures	Risk of venous air embolism
'Tuck Seat'[213]	As for 'Tuck' position, but padded seat below ischial tuberosities	As for 'Tuck' position Risk of crush injury and deep venous thrombosis low	
Evacuatable Mattress[183]	Airtight flexible mattress Becomes rigid on evacuation. Moulded around patient to support iliac crests and thorax but with abdomen free	Fewer pressure effects (spreads load over whole body) Adjustable for any body habitus. Heat-retaining	
Prone lithotomy[180]	Lithotomy position of legs superimposed on prone position	Some compensation for impaired venous return Good access for ano-rectal surgery	Rarely used, hence limited data available

in a convex saddle frame caused a decrease in CI and stroke volume index with no significant increase in IVC pressure. It was suggested that in these situations, the position of the heart at a hydrostatic level above the head and limbs may have caused reduced venous return to the heart and consequently a decreased CI. A study[207] of four different surgical prone positions in 20 healthy non-anaesthetized volunteers (support on pillows under the thorax and pelvis with abdomen free, on an evacuatable mattress, on a modified Relton–Hall frame and the knee–chest position) found no substantial changes in heart rate or MAP in any position, but CI decreased by 20% on assuming the knee–chest position and by 17% on assuming the modified Relton–Hall position. In the prone jack-knife position,[70] head-down tilt caused CI to return to supine values, attributed to decompression of the IVC allowing an increase in venous return to the heart.

It has been suggested that the decrease in CI could be attributed to increased intra-thoracic pressures causing a decrease in arterial filling, leading to an increase in sympathetic activity via the baroceptor reflex. Consistent with this theory is the work which demonstrated decreased stroke volume accompanied by an increased sympathetic activity (increased heart rate, total peripheral vascular resistance, and plasma noradrenaline) in prone patients.[153] Another study has suggested that in addition to reduced venous return, left ventricular compliance may also decrease secondary to increased intra-thoracic pressure which could contribute to the observed decrease in cardiac output.[182]

Recent work suggests that the anaesthetic technique could affect haemodynamic variables in the prone position. One study[142] compared total i.v. anaesthesia (TIVA) with inhalation anaesthesia by measuring MAP and heart rate in patients undergoing spinal surgery. A greater decrease in arterial pressure in the TIVA group was observed. A study[182] comparing inhalation with i.v. maintenance anaesthesia used non-invasive cardiac output measures with the patients supine and then prone on a Montreal mattress. The authors found a decrease in CI and increase in SVR on turning the patient prone. The changes were greater during TIVA (decrease in CI of 25.9%) than during inhalation anaesthesia (12.9%). However, a contributor to these observations could be a change in propofol pharmacokinetics in the prone position. Measured propofol concentrations have been observed to increase during target-controlled infusions when patients are transferred from supine to prone, probably as a result of the decrease in cardiac output.[189]

Inferior vena caval obstruction

Obstruction of the IVC is likely to play a role in reducing cardiac output in at least some patients positioned prone. It is also clear that such obstruction contributes to increased blood loss during spinal surgery. Obstruction to venous drainage forces blood to return to the heart by an alternative route (usually the vertebral column venous plexus of Batson). As these veins are thin walled, containing little or no muscle tissue and few valves, any increase in pressure is transmitted and causes distension. This is likely (especially during lumbar spinal surgery) to cause increased blood loss and difficulty with the surgical field.

The problem of IVC obstruction is well recognized and various methods have been attempted to reduce blood loss, including the use of local anaesthetic infiltration, spinal and epidural anaesthesia, and deliberate hypotension. In one study,[144] IVC pressure was measured in six patients with the abdomen hanging free or compressed. In all patients, abdominal compression resulted in a large increase in venous pressure, increasing to more than 30 cm H_2O in one patient. The position resulting in the

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least compression (changes of up to 4 cm H_2O) involved placing a large block under the chest and small sandbags under each anterior superior iliac crest. It was also noted that hypercarbia and any increase in pressure during expiration caused an increase in venous pressure.

A comparison of IVC pressures found that patients in the flat prone position had pressures 1.5 times greater than in patients on the Relton–Hall frame,[105] demonstrating the benefit of a support system allowing a free abdomen. This study also found that induced hypotension had no significant effect on IVC pressure.

In summary, turning a patient into the prone position has measurable effects on cardiovascular physiology, the most consistent of which is a reduction in CI. This has variously been attributed to reduced venous return, direct effects on arterial filling, and reduced left ventricular compliance secondary to increased thoracic pressure. Other haemodynamic variables change less predictably, although at least some patients demonstrate an increased sympathetic response to the change in position, and choice of anaesthetic technique may influence the degree to which such changes occur. Obstruction of the IVC is a well-recognized complication of prone positioning and is exacerbated by any degree of abdominal compression, leading to decreased cardiac output and increased bleeding, venous stasis, and consequent thrombotic complications. Careful positioning is therefore essential to minimize these risks.

Changes in respiratory physiology

Lung mechanics have been studied in different positions, and interest has grown in the use of the prone position for improving oxygenation in patients with acute lung injury. This review does not address the changes occurring in the intensive care setting. It should be noted that studies carried out on awake spontaneously breathing subjects cannot necessarily be extrapolated to those who are anaesthetized and ventilated. In addition, the type of frame or support used and the body habitus of the patient may influence results.

Lung volumes

The most consistent finding is a relative increase in functional residual capacity (FRC) when a patient is moved from a supine to a prone position; forced vital capacity and forced expiratory volume in 1 s (FEV1) change very little.[115] Coonan and Hope[33] have discussed in detail the cardio-respiratory effects of change in body position. The change in FRC in a patient going from upright and conscious to supine, anaesthetized, and paralysed is a decrease of 44%, but from upright to prone is considerably less at 12%. These findings were confirmed in a clinical context in patients undergoing intervertebral disc surgery.[145] Measurements of FRC and arterial oxygen tension (Pa_{O_2}) were made with patients supine and again after 20 min prone. On changing from supine to prone there was a significant increase in the FRC and Pa_{O_2} [1.9 (SD 0.6) *vs* 2.9 (0.7) litre and 160 (37) *vs* 199 (16) mm Hg]. The delivered tidal volumes and inspiratory flow rates were unchanged by the position, as were the static compliances of the respiratory system (chest wall and lung). Although the resistance of the respiratory system was found to increase by 20% primarily as a result of changes in the viscoelastic properties of the chest wall, this did not seem to be of any clinical significance. Airway resistance was not altered with the change in position. The authors related the increase in FRC to the reduction of cephalad pressure on the diaphragm and the reopening of atelectatic segments.

The study was repeated in obese patients (BMI>30 kg m^{-2}),[146] using similar methodology and positioning, and found an increase in lung volumes, lung compliance, and oxygenation when patients were turned into the prone position, although the average FRC in obese subjects when supine was significantly smaller than in the non-obese group [1.9 (0.6) litre compared with 0.894 (0.327) litre].

It should be noted that some older work came to different conclusions, based on findings of marked (30–35%) decreases in respiratory compliance and increased peak airway pressure.[116 163] However, the position used by these authors was either inferior in terms of allowing free abdominal and chest wall movement[116] or not described.[163] It is clear that observed changes in lung volumes will depend on the exact prone position used. This has been demonstrated in one study[118] which compared lung volumes in three different prone positions (knee–chest, Eschmann frame, and chest/pelvic supports) with those in a 'control' prone position in 10 healthy non-obese subjects who were awake, breathing spontaneously. In all positions, the FRC tended to increase compared with control (significantly in the knee–chest and frame positions). Overall, the knee–chest position allowed the largest lung volumes with the exception of the inspiratory capacity which decreased significantly compared with the control. The cause of the improvement in lung volumes is thought to be the weight being supported by the knees, allowing the lower chest and abdomen to be suspended. However, these findings cannot necessarily be extrapolated to the anaesthetized ventilated patient.

Distribution of pulmonary blood flow

Early studies described redistribution of pulmonary blood flow to dependent lung areas when patients were moved from supine to prone.[87] More recently, it has been observed in animal studies that regional perfusion is directed preferentially towards the dorsal lung areas regardless of position.[55] Work in humans has similarly shown attenuation of the preferential perfusion of dependent lung areas in prone compared with supine positioning; one study found that lung perfusion was more uniformly distributed in the prone compared with the

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supine position.[136] These findings are consistent with the theory that gravity has only a minor role in determining regional lung perfusion; an intrinsically lower pulmonary vascular resistance in dorsal regions of lung could be the explanation. In the prone position, blood flow may be relatively uniform as gravitational forces are opposing rather than augmenting the regional differences in pulmonary vascular resistance. The role of gravity in the distribution of pulmonary blood flow has recently been reviewed and lung architectural changes may be more important.[52]

Distribution of ventilation

Redistribution of lung ventilation is another proposed mechanism by which gas exchange is thought to improve in the prone position. Work carried out in the 1960s[87] demonstrated the apparent dependence of both ventilation and perfusion on gravity. However, it is now suggested that variation in regional lung ventilation may be related primarily to the structural features of the airways and blood vessels and that gravity has a less important role. Early studies[87] suggested that the greater ventilation observed in the dependent lung was secondary to gravitational differences in interpleural pressure (IPP), IPP becoming less sub-atmospheric with gravity. Both animal and human studies have subsequently shown that the pleural pressure gradient when prone is considerably reduced compared with supine.[121 132] This reduction in pleural pressure gradient is thought to be caused by the action of gravity on mediastinal and abdominal contents and the shape of the chest wall.[197] Findings suggesting a more even vertical distribution of ventilation in the prone position are common[10 83] but not universal and some authors have found ventilation to remain heterogeneous in the prone position.[159] Such evidence and the persistence of ventilation heterogeneity at the same vertical level and in the absence of gravity has led a recent review to suggest that pulmonary vascular and bronchiolar architecture may be more important than gravity in supine and prone positions, in determining ventilation and perfusion distribution.[52]

In summary, there are clear differences in respiratory physiology between the supine and prone position, including an increase in FRC and alterations in the distribution of both ventilation and perfusion throughout the lungs. It is thought that this leads to improved ventilation/perfusion matching and consequently improved oxygenation in the surgical patient.

Complications associated with the prone position

Injury to the central nervous system

Injury to the central nervous system represents a rare but potentially catastrophic complication of the prone position. These injuries can be classified according to the underlying mechanism—arterial occlusion, venous occlusion, air entrainment, cervical spine injury, or the effect of undiagnosed space-occupying lesions.

Injuries from arterial occlusion

Turning a patient from the supine to the prone position should be performed carefully, avoiding excessive neck movement and allowing normal blood flow in the carotid and vertebral arteries. Failure to observe these precautions can lead to serious complications. Injury to the carotid arteries seems relatively uncommon. A patient developed a permanent right hemiparesis and aphasia 1 day after uneventful spine surgery and dissection of the left internal carotid artery was diagnosed, with infarction of the left middle cerebral artery territory.[59] The mechanism was unclear, but was thought to involve unrecognized extension or rotation of the neck during positioning. A patient with unrecognized carotid stenosis who suffered a fatal stroke after spine surgery positioned prone with the head rotated has been reported.[210]

Occlusion of the vertebral arteries has been reported in at least four cases. In one,[31] an underlying asymptomatic stenosis of the distal right vertebral artery led to hypoperfusion in those areas of the brain supplied after rotation or extension of the neck. The patient developed a lateral medullary syndrome immediately after surgery, but with anticoagulation and rehabilitation made a good recovery. The other three case reports involved patients with apparently normal vascular anatomy. One[100] patient developed a sudden quadriplegia within a few hours of surgery in the knee–chest position with the head rotated. MRI scanning demonstrated infarcts in the upper cervical cord and at watershed areas between anterior and posterior cerebral circulations, but normal vertebrobasilar vessels. The authors proposed that temporary occlusion of the vertebral artery led to stasis, thrombosis, and subsequent embolism when the occlusion was released, and emphasized the need to maintain normal neck alignment in the prone position. A review of postoperative brainstem and cerebellar infarcts[193] includes a single case report with a similar mechanism occurring during scoliosis repair and therefore presumably while the patient was prone. A patient who also underwent surgery with the head rotated developed a vertebral artery dissection with a cerebellar infarct.[171] As most of these cases involved positioning prone with the head rotated, it would seem prudent to maintain neutral neck alignment to minimize the risk of occluding the carotid or vertebral arteries.

Injuries from venous occlusion

Four patients who underwent cervical laminectomy in the prone position supported by chest rolls developed new neurological deficits immediately after operation (two hemipareses, one quadriparesis, and one paraparesis).[18] In each patient, the cause was not apparent; any arterial

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hypotension was mild and transient, immediate CT myelography and surgical exploration were unremarkable, and all four patients slowly improved after treatment with steroids and induced hypertension. The authors proposed that the use of chest rolls caused a degree of increased venous pressure, which, when combined with mild arterial hypotension, led to a decreased perfusion pressure in the spinal cord and ischaemia. A similar mechanism may explain a quadriplegia[37] which occurred after thoracolumbar decompression, and two reports of thoracic level paraplegia after lumbar spine surgery.[201] In these seven patients, the venous anatomy was apparently normal. Two reports of injury involving venous occlusion occurred in the context of abnormal venous anatomy. A man with achondroplasia[48] who underwent thoracolumbar surgery in the prone position developed bilateral venous infarcts in the cerebellum. This was thought to result from stenosis of the jugular foramina (a recognized feature of achondroplasia) which had been asymptomatic until the patient underwent 9 h of surgery head-down on a Wilson Frame, with high intra-thoracic pressures during positive pressure ventilation. In a patient with an occipital meningioma which had obliterated the superior sagittal sinus, such that venous drainage from the cerebral hemispheres occurred through anterior emissary veins into the scalp, placement prone on a horseshoe head-rest caused compression of these veins leading to venous stasis and rupture into the frontal extradural space.[25] Prompt evacuation prevented any residual deficits, but the authors observed that this complication could have been avoided with the use of three-pin fixation instead of a horseshoe rest.

Air entrainment

Entrainment of air into the cranial cavity is common after neurosurgical procedures, and occurs in all operative positions. Toung and colleagues[198] noted pneumocephalus in 16 of 28 patients undergoing posterior fossa or cervical spine procedures in the prone position. Given the frequency with which this occurs, it is surprising how rarely tension pneumocephalus has been observed, with only two cases reported.[137 223] This is in contrast to the sitting position, where tension pneumocephalus is a well-recognized but infrequent complication. There is a single case report[151] of quadriplegia as a result of pneumorrhachis (air entrainment into the spinal canal) after posterior fossa exploration. This was postulated to have occurred as a result of a head-down position, allowing entrapped air in the posterior fossa to pass through the foramen magnum. Supportive treatment led to complete resolution of the symptoms.

Cervical spine injury

It is generally accepted that careful positioning of the neck is essential to prevent neurological injury in the prone position. It is reassuring to note the infrequency with which these injuries have been reported. Excessive neck flexion in a patient undergoing an 8.5 h operation in the 'Concorde' position with the neck flexed and the chin approximately one finger-breadth from the sternum,[154] resulted in complete and permanent C5/6 sensory and motor deficit level after operation. This was presumed to result from overstretching of the cervical cord in a narrow spinal canal and a bulging C5/6 disc, with consequent ischaemia. A patient undergoing lumbar spine surgery awoke with a T6 sensory level as a result of a prolapsed intervertebral disc at C6/7.[26] Excessive neck extension together with the muscle relaxation of general anaesthesia was blamed, although this could conceivably have occurred during tracheal intubation. Dislocation injuries of the cervical spine seem to be extremely uncommon; two patients are described with pre-existing cervical spine dislocations who were nursed on a Stryker Frame and whose dislocations recurred when turned from supine to prone.[174] However, *de novo* dislocation has not been described.

Undiagnosed space-occupying lesions

Although rare, space-occupying lesions within the spinal canal or cranial cavity can become symptomatic as a result of prone positioning, including spinal arachnoid cysts,[204] spinal metastases,[91] and frontal lobe tumours.[54] In each case, the mechanism involved was uncertain but the temporal relationship to the prone position strongly implicates it. Altered CSF flow dynamics and epidural venous engorgement could have been responsible. A patient with neurofibromatosis has also been described in whom an undiagnosed pedunculated neurofibroma in the posterior fossa fell anteriorly when prone, compressing the medulla and pons and leading to a bradycardia and fatal neurogenic pulmonary oedema.[205]

Injury to the peripheral nervous system

Peripheral nerve injury may occur in patients under anaesthesia in any position and is thought to be the end result of nerve ischaemia from undue stretching or direct pressure. However, prone positioning might be expected to lead to a different pattern or frequency of nerve injury when compared with supine positioning.

Frequency of peripheral nerve injury

The frequency of peripheral nerve injury after surgery in any position has been addressed in a number of retrospective studies. One examined the notes of 30 000 patients between 1940 and 1945 and found 31 episodes of paresis after surgery (0.1%), none of which appeared to follow the use of the prone position.[40] Parks[143] published a review of 50 000 procedures (including general and cardiac surgery, but not obstetrics) of which 72 were linked with peripheral nerve complications (0.14%), three of which followed prone positioning. However, neither study gave the denominator value. Others have looked for any association between specific patient positions and nerve injury. In one

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large study, over a million surgical episodes were reviewed; 414 patients developed an ulnar neuropathy after operation and no association was found with intraoperative position.[211] In the first[95] of two reports based on the ASA closed claims database, an association between prone positioning and claims for nerve injury was noted, but in the second[27] no comment was made.

The use of somatosensory evoked potentials (SSEP) as an indirect indicator of potential injury has been proposed as a useful detector of positioning-related nerve injury, although it is not yet accepted as a reliable surrogate marker. In a study of 14 volunteers positioned prone while awake, three developed upper limb neurological symptoms without changes in evoked potential monitoring,[114] and a further four developed symptoms with SSEP changes. Another study reported six patients with postoperative neurological deficits, despite unaltered evoked potentials intraoperatively.[107] However, the only studies that directly address the risks of peripheral nerve injury in different operative positions have done so using SSEP monitoring as a surrogate. In 1000 consecutive spinal operations in patients in five different surgical positions, SSEP monitoring of the upper limbs[85] found that the 'prone superman' and lateral decubitus positions had the highest frequency of reversible (position-related) SSEP changes at 7.0% and 7.5%, respectively. In contrast, the prone position with arms tucked by the patient's side caused changes in only 2.1% of patients. Overall, position-related SSEP changes occurred in 6.1% of patients (all reversible). No patients developed a new neurological deficit after operation.

Distribution of peripheral nerve injuries

In the upper limb, at least four cases have been reported of brachial plexus damage occurring after prone positioning intraoperatively[13 79 169 220] and two in the intensive care setting.[56] One of the patients undergoing surgery in theatre sustained a bilateral brachial plexus palsy after the arms had been extended in the prone position for spinal fusion.[220]

It has been suggested that the prone patient may tolerate arm abduction better than the patient who is supine,[2] although this is not accepted by all.[220] Of note, both brachial neuropathy and SSEP changes have occurred after prone positioning where the arms were abducted only to 90°.[79 85] Two patients undergoing surgery in the '3/4 prone' position and monitored using median nerve SSEP developed SSEP changes that were corrected by altering patient positioning. It was proposed that this position puts both brachial plexuses at risk, one stretched by flexion and rotation of the neck, the other by pressure against the upper shaft and head of the humerus.[119]

In the upper limb, ulnar neuropathy has occurred in prone patients; of a series of 414 patients who developed postoperative ulnar neuropathy, eight had been prone; no association of injury with position was found.[211] A case report of an isolated axillary nerve injury occurring during lumbar spine surgery[65] attributed this to the arms being abducted above the head. Musculocutaneous[3] and radial nerve injury[143 167] have also been reported.

In the lower limb, evoked potential monitoring is used less frequently. There is one report of sciatic nerve injury[120] in a patient placed prone for 8 h undergoing a mitral commissurotomy. Damage to the lateral cutaneous nerve of the thigh is a much more commonly recognized complication of prone positioning in case reports[143] and prospective studies (23.8% of patients undergoing surgery on a Relton–Hall frame developed evidence of nerve injury).[224]

A single report describes damage to lingual and buccal nerves (thought to have been stretched between masseter muscles as a result of inadvertent jaw retraction in the prone position).[221] Three patients have sustained injury to the supra-orbital nerve[75 222] and over-extension or rotation of the neck while prone is thought to have caused injury to the phrenic nerve[208] and the recurrent laryngeal nerve.[138] One case series describes injury to the dorsal nerves of the penis in two patients prone on a fracture table.[74]

Risk of peripheral nerve injury

Before operation, it seems sensible to assess the patient's ability to tolerate the proposed operative position while they are awake.[2 13] This logic has been followed further by those who assist the patient to position themselves pre-induction. In a case report of nerve injury after operation, it transpired that the patient had suffered the same symptoms after previous surgery, although had not volunteered this.[65] In at risk patients, for example, those with diabetes, peripheral vascular disease, alcohol dependency, pre-existing neuropathy, and anatomical variants,[220] direct questioning with regard to postoperative neurological problems might elicit such a history.

Intraoperatively, SSEP monitoring is used in some centres for detection of impending injury. As in any position, care with padding and arm positioning is recommended. There is disagreement over the degree of abduction for the arms in the prone position,[2 13 85] with some advocating the arms by the sides wherever possible[220] or intermittent movement of the patient's arms under anaesthesia, although, as yet, there is no evidence to support this latter suggestion.

After operation, it has been suggested that ulnar nerve function should be tested clinically on recovery after operation.[211] If a neurological deficit is suspected, further investigation including electromyographic studies is indicated. It is of note that when analysing the closed claims data, the ASA reviewers felt that an appropriate standard of care was met in the majority of cases.[95] Because the mechanism of injury is not well understood, it is hard to see how any more can be done to prevent such damage. In those cases where reviewers felt that there were remediable

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causes of injury, these often related to padding and arm positioning.

Pressure injuries

A wide variety of injuries can occur in the prone position as a result of the application of pressure to dependent parts of the body. These injuries can be thought of as being the result of either *direct* pressure or *indirect* pressure (when the injury occurs as a result of pressure on, or occlusion of, the vascular supply).

Direct pressure injuries

Pressure necrosis of the skin: Direct pressure is a common cause of anaesthesia-related injury which can occur in the prone position, with most authors advising close attention to positioning of the face, ears, breasts, genitalia, and other dependent areas to prevent pressure sores or skin necrosis. However, there are few reports of this complication occurring and it is usually mentioned only as part of case series of other complications. Affected skin areas include the malar regions, iliac crests, chin, eyelids, nose, and tongue.[12 45 80 129 155 162 176 216]

It is not clear why there should be so few reports of a complication that is quoted in standard textbooks. It would be encouraging to believe that anaesthetists are so diligent in their positioning that the complication has been effectively abolished. It may be that the tissues are more resistant to pressure than is realized, and that the duration of a typical surgical procedure in the prone position is not long enough for pressure injury to occur. Alternatively, lack of reports may represent a bias in publication—pressure injury is regarded as a 'recognized hazard', even though there has been no prospective study to document its incidence.

Contact dermatitis: A patient developed contact dermatitis of the face[82] with periorbital and lip swelling after undergoing surgery with the head placed in the PronePositioner™ (Voss Medical Products Inc., San Antonio, TX, USA). This device is made of flexible polyurethane foam to support the face during prone surgery by moulding around the eyes, nose, and mouth. The patient had undergone multiple procedures with this device, and the authors proposed that he had become sensitized to it, but no formal allergy testing was done. A case of contact dermatitis in response to a Bispectral Index® monitor placed on the forehead was thought to have been exacerbated by the prone position, continued pressure causing more contact with the electrode conductive gel.[150]

Tracheal compression: There have been four reported cases of tracheal compression occurring during surgery in the prone position.[17 84 125 158] In all patients, this was associated with thoracic scoliosis, and the proposed mechanism involved a reduced anterior–posterior diameter of the chest, which resulted in compression of the trachea between the spine and the sternum. Interestingly, in three of the four patients, the problem was exacerbated by an underlying connective tissue defect of the trachea, either Marfan's syndrome[84 125] or tracheomalacia.[158] Tracheal compression appears only to be a problem in patients with underlying anatomical abnormalities, and has not been reported in those of a normal habitus.

Salivary gland swelling: Bilateral painful swelling of the submandibular glands after surgery in the prone position with the head rotated[67] has been reported. Although the aetiology is not clear, the authors concluded that it probably resulted from stretching of the salivary ducts, leading to stasis and acute swelling. A similar mechanism may explain a series of six cases of 'anaesthesia mumps',[92] five of which occurred after prone surgery, although venous stasis may also have been responsible.

Shoulder dislocation: The distribution of pressure in the prone position can also lead to anterior dislocation of the shoulder. This has been reported in a patient undergoing spinal fusion for trauma,[9] whose injuries also included bilateral shoulder dislocations. These had been reduced before surgery, but one dislocated again when the arm (positioned abducted at 90° at the shoulder) was moved intraoperatively. This was only noticed because it led to compression of the axillary artery and loss of the pressure trace in a radial arterial cannula. There were no sequelae after prompt relocation. Anterior dislocation also occurred in an elderly, debilitated patient after positioning with the arms abducted and externally rotated.[71] Occasional isolated cases of shoulder joint pain have also been reported in larger series of patients operated on in the prone position.[186]

Indirect pressure injuries

Macroglossia and oropharyngeal swelling: Macroglossia is a well-documented complication of surgery in the sitting position and is thought to result from excessive flexion of the head and neck causing obstruction to venous drainage. However, there have been three reports of its occurrence after surgery in the prone position. One[148] described a patient who developed massive swelling of the tongue, soft palate, lateral pharynx, and arytenoids after a 4 h suboccipital craniotomy for an Arnold-Chiari malformation. Extubation had to be delayed for 72 h, but there were no long-term sequelae. However, the patient had required three attempts at tracheal intubation and also had an orogastric tube and oesophageal temperature probe inserted, so local trauma possibly contributed to this swelling. In contrast, a second case also with an Arnold-Chiari malformation undergoing posterior cervical spine decompression lasting 6 h,[172] involved a single easy attempt at intubation and no further upper airway instrumentation. Swelling of the tongue and oropharynx occurred after surgery and required emergency tracheostomy to relieve upper airway obstruction. The swelling subsided after 5 days, and again there were no long-term sequelae. A third case has also recently been described.[200]

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The proposed mechanism for this complication suggests that excessive flexion of the head and the presence of a tracheal tube cause kinking and obstruction of the internal jugular vein in the neck, which in turn obstructs venous drainage from the lingual and pharyngeal veins. In a small study, a significant increase in postoperative upper airway oedema was observed in patients operated on in the prone position compared with supine, albeit with no untoward sequelae.[187] A common feature of the published case reports seems to be anatomical abnormalities of the skull base, which might predispose to venous obstruction in a position which would be tolerated by normal subjects.

Mediastinal compression: The chest wall is usually sufficiently robust to allow the patient's weight to be supported on it without compression of the structures within. However, this cannot necessarily be assumed in the presence of congenital anatomical abnormalities or after cardiothoracic surgery. Scoliosis often results in a reduced anterior–posterior diameter of the chest, so it is unsurprising that there are reports of the cardiac output being lost during surgical manipulations of the spine,[227] probably due to compression of the heart and great vessels. In pectus excavatum, this is more pronounced and can occur without any additional force. Two case reports describe severe hypotension resulting from compression of the right ventricle against an abnormal sternum. In one, intraoperative transoesophageal echocardiography allowed bolsters to be placed longitudinally to avoid this problem, and surgery proceeded uneventfully thereafter.[8] The second case could only be managed by returning to the supine position, although not before myocardial ischaemia had occurred.[192]

After cardiac surgery, there has been a single case report of compression and occlusion of an aorto-coronary vein graft,[215] leading to myocardial ischaemia during lumbar spine surgery. Another case report documented the transient obstruction of a Rastelli conduit in a patient with repaired Tetralogy of Fallot during surgical manipulation of a scoliotic spine.[72]

Visceral ischaemia: As well as avoiding abdominal compression to improve the surgical field, compression on the abdominal organs must be avoided. Hepatic ischaemia, with progressive metabolic acidosis and elevated liver enzymes, has been described after prolonged surgery in the prone position,[227 228] with subsequent resolution and a case of hepatic infarction after 10 h of surgery in the prone position.[165] This complication may be more common than published reports would suggest and was recently investigated by the UK National Patient Safety Agency; at least five other cases were identified.

Pancreatitis is a recognized complication of scoliosis surgery, causally related to systemic factors such as hypotension, blood loss, drug effects, or the use of a cell-saver. However, pancreatitis has occurred in the absence of any other obvious cause,[35] and the authors concluded that the prone position was probably responsible.

Avascular necrosis of the femoral head: Three patients,[139] with preoperative radiological signs of osteoarthritis of the hip, underwent decompressive surgery for spinal stenosis in the prone position using a hypotensive anaesthetic technique, and developed collapse of the femoral head in five hip joints, consistent with avascular necrosis, within 2–8 weeks. The cause was thought to be a combination of deliberate hypotension and increased venous pressure from the prone position leading to intraosseous hypertension and ischaemia of a compromised femoral head. This has not been described after hypotensive anaesthesia in other positions, suggesting that the prone position played a role in its pathogenesis.

Peripheral vessel occlusion: The prone position can cause compression and occlusion of a number of peripheral vessels. Compression of the axillary artery has been detected by pulse oximetry[173] or radial artery monitoring[9] on the affected arm. In a patient[206] with scoliosis positioned on a four-post (Relton–Hall) spinal frame, SSEP from the posterior tibial nerve were suddenly lost intraoperatively, accompanied by mottling of one leg and absence of the dorsalis pedis pulse. Repositioning restored all observations to normal. It was thought that the pelvis had shifted laterally on the frame and occluded the femoral artery. A patient having posterior spinal fusion on a similar frame developed signs and symptoms of acute unilateral lower limb ischaemia after complete occlusion of the external iliac artery 3 h after operation.[4] Emergency thrombectomy restored flow, and there were no long-term sequelae. Pressure from the frame posts on the inguinal region was proposed as a cause.

Limb compartment syndromes and rhabdomyolysis: In a study of unanaesthetized volunteers in the knee–chest position,[98] investigators used ultrasonography of the posterior tibial artery to demonstrate a reduction in arterial blood flow velocity of up to 31%. In addition, no flow in the posterior tibial vein was found in 10 of 21 subjects. In studies of the pathogenesis of crush syndrome,[140] measurement of i.m. pressures in a variety of positions, including the 'Tuck' position,[214] found a mean pressure of 108 mm Hg in the anterior compartment of the leg on a soft surface, rising to 142 mm Hg on a hard surface. The authors noted that pressures of 30–50 mm Hg were sufficient to render muscles ischaemic. There is biochemical evidence of muscle damage after surgery in the prone position, and one study[36] found a significant increase in plasma creatine phosphokinase levels in all 15 patients undergoing surgery for spondylolisthesis in the knee–chest position. In addition, myoglobinaemia and myoglobinuria were detected in six. There have been seven cases of compartment syndrome reported in English language journals[15 53 57 89 97] and one in French.[34] In all eight, the patients were undergoing spinal surgery in some variation of the prone position which involved flexion of the hips and knees, and surgery lasted longer than 3 h in at least six cases. Six patients needed fasciotomies, and three cases were complicated by acute renal failure, this being

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fatal in one patient. It would seem, therefore, that this is associated with flexion of the hips and knees and resultant impaired blood flow. In addition, there have been at least four cases reported of rhabdomyolysis in the absence of compartment syndrome,[34 50 152] involving prolonged (>5 h) spinal surgery with flexion of the hips and knees. Three of the four patients were obese, suggesting that increased pressure on the anterior thighs was responsible and one patient developed acute renal failure, but no mortality was associated with the condition. Upper limb compartment syndrome has never been described, although the reports already discussed involving axillary artery occlusion may have progressed to this had they not been detected.[9 173]

Ophthalmic injury

Postoperative visual loss (POVL) after non-ocular surgery in any position is relatively rare. One retrospective study of 60 695 patients found 34 eye injuries (mostly corneal abrasion) of which only one, who had been positioned prone, developed postoperative blindness.[161] Similarly, a subsequent study of 410 189 patients estimated the general postoperative risk of prolonged visual loss as 0.0008%.[212] In these two large groups, prone positioning was not implicated as an independent risk factor for ophthalmic injury. However, other work suggests that spinal surgery performed prone may be associated with ophthalmic injury. A retrospective review of 3450 spinal operations demonstrated that 0.2% of patients developed visual loss after operation.[181] In 2003, the ASA POVL Registry, based on clinical reporting, found that 67% of all reported cases of POVL followed prone spinal surgery.[103]

The two injuries most commonly described are ischaemic optic neuropathy[73 86] and central retinal artery occlusion.[63 66] Other complications which have been observed in the prone, anaesthetized patient include supraorbital neuropraxia, occurring in three patients associated with other injury,[75 222] transient and permanent ophthalmoplegia in nine patients[66 75 96 218 222] and single case reports of cavernous sinus thrombosis,[11] central retinal vein occlusion,[181] unexpected presentation of an orbital haemangioma,[60] painful orbital compartment syndrome,[106] bilateral angle closure glaucoma,[58] non-traumatic subperiosteal orbital haemorrhage,[225] amaurosis,[88] dislocated intraocular lens[93] and fixed mydriasis.[23] Studies have been conducted examining keratoconjunctival injury[19] and postoperative chemosis[81] both of which have been observed after prone positioning.

Aetiology

There are a number of mechanisms by which prone positioning may lead to ophthalmic injury. The most obvious is the effect of direct external pressure by a headrest or other support on the orbital contents causing an increase in intraocular pressure which may lead to retinal ischaemia and visual loss. This has been named 'Hollenhorst syndrome' and is usually linked with examination findings consistent with central retinal artery occlusion. Ironically, such injury has recently been described as a result of the use of a device designed to protect the eyes.[162]

POVL can occur in the absence of external impingement on the eyeball, for example, where the head has been pinned and no headrest or other support has been in the vicinity of the eyes. This situation tends to be associated with findings of ischaemic optic neuropathy on examination[102] and may also be bilateral (over 40% of patients in one review).[73] The final common pathway in ischaemic optic neuropathy is inadequate oxygenation of the optic nerve causing ischaemic damage and failure of impulse transmission. Some individuals may be susceptible to this as a result of anatomical variation in the arterial supply or abnormal autoregulation of that supply.[160] In any patient, however, oxygenation of the optic nerve is dependent on adequate perfusion of its component neurones. Perfusion pressure to the optic nerve can be defined as the difference between MAP and intraocular pressure or venous pressure, whichever is the greater. Consequently, an increase in intraocular or venous pressure or a decrease in arterial pressure can increase the likelihood of developing optic nerve ischaemia.

Increased intraocular pressure has been demonstrated in both the awake and anaesthetized prone patient in the absence of extraocular pressure on the globe.[30 141] Duration in the prone position may also be relevant, intraocular pressure tending to increase with time,[30] but not all studies have demonstrated this.[77] As in the case of intracranial pressure, a variety of factors influence intraocular pressure and some of these are clearly altered by prone positioning. Prone positioning tends to increase venous pressure and peak inspiratory pressure which in turn increase intraocular pressure.[30] This increased orbital venous pressure (as there are no valves between this system and the central venous circulation), decreased choroidal blood flow and reduced outflow of aqueous humour could decrease perfusion pressure to the optic nerve head and contribute to ischaemic optic neuropathy.[41] A variety of other mechanisms contributing to increased intraocular pressure have been suggested,[141] including impaired arterial autoregulation under anaesthesia leading to an increase in intraocular blood volume, altered circulation of aqueous humour and the administration of large volumes of i.v. fluids.[73] A recent review[102] of 93 episodes of POVL after spine surgery discussed the role of venous pressure in the aetiology of ischaemic optic neuropathy.

MAP may decrease in the prone position either as a result of a deliberate hypotensive technique, secondary to hypovolaemia or a decrease in cardiac output from abdominal compression. Although POVL can be associated with hypotension, deliberate or otherwise, this is not always the case.[104] Visual loss after prone anaesthesia and surgery is often characterized by long surgical duration, large blood loss, and administration of large volumes of clear fluids.[102] Other factors which could increase the risk

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of developing ischaemic optic neuropathy include vascular disease such as atherosclerosis, diabetes, and pre-existing hypertension. It should be noted, however, that a number of events occur in those without such risk factors.[28]

Minimizing risk

It is likely that some patients are more at risk either by virtue of pre-existing disease or the nature of their surgery. Whether the anaesthetist should deliberately aim to maintain intraocular perfusion and oxygenation by maintaining a minimum systemic pressure, by increasing the transfusion trigger in high-risk patients,[86] or by manipulating intraocular pressure is not yet clear. Certainly, there is a duty to avoid external pressure on the eye by careful attention to head positioning on headrests or rings, and interim checks of the eyes may be indicated, although these could increase the risk to the patient. The importance of head positioning to maximize venous outflow from the eye and hence minimize any impairment of ocular perfusion has been noted. It may also be the case that in high-risk patients, keeping the head above the heart by means of a slight head-up tilt can reduce risk.[141]

Some authors have suggested preoperative counselling for all patients,[29] or selectively for those groups deemed to be at high risk.[1 86] Others recommend routine eye checks in recovery;[29 181] some patients have been delayed in their presentation by a feeling that blurred vision is 'to be expected' after major surgery. Whether earlier detection would make any difference to outcome is unclear. Not all patients experience symptoms immediately after surgery.[133]

There are few specific treatments available and usually the damage is irreversible. A variety of options have been tried, including urokinase, PGE1, hyperbaric oxygen therapy, and stellate ganglion block in one patient with central retinal artery occlusion[188] with varying degrees of success. In general, it has been suggested that correction of any potential causes of decreased oxygen delivery is the best option where POVL is detected early.[29]

Ophthalmic complications are well recognized in patients who have been prone under anaesthesia and can be devastating. Some are preventable by clearly recognized precautions but others are harder to avoid because the mechanism of injury is less well understood. It can be argued that in those patients at high risk by virtue of having pre-existing vascular disease and undergoing prolonged surgery in the prone position where large fluid shifts can be expected, preoperative counselling should be undertaken to ensure their understanding of POVL as a potential risk.

Embolic complications

Venous gas embolism

Venous gas embolism (VGE) may result from atmospheric air entrainment or accidental direct delivery of exogenous gas. Efforts to minimize abdominal compression and thus IVC pressure in the prone position can result in an increased negative pressure gradient between right atrium and veins at the operative site. This increases the risk of air entrainment. Risks are minimized by maintaining intravascular volume and pressure and (where possible) positioning the surgical site dependent relative to the heart. In the prone position where the abdomen is free, intrathoracic and intra-abdominal pressures are reduced; vena caval pressures may be as low as -2 cm H_2O.[43] This negative pressure could then move gas along the gradient of 10–15 cm H_2O from the operative site to the right atrium.

A variety of estimates have been made of the frequency of VGE in the prone position; one review of 107 paediatric patients undergoing 120 neurosurgical operations found only two possible episodes (1.7%).[124] At present, the true incidence is not known and as highlighted in a recent review,[127] it may never be clear because of the variable sensitivity of detection methods in current use. In an effort to clarify the issue, a central registry for VGE reporting has been set up.[7] There have been a large number of case reports of VGE in the prone position (Table 2). A recent review notes the usefulness of the correctly placed multiorifice right atrial catheter as a means of aspiration of gas emboli,[127] although there are now no formal data to support the insertion of central venous catheters in the setting of acute haemodynamic compromise.

Non-gaseous embolism

The majority of reports in the literature are concerned with VGE (air or oxygen) but reports also exist of fat, cement, and bone fragment emboli. It is not clear in the latter cases whether the complications are specific to the prone position or would have resulted anyway from the nature of the surgery regardless of position.[128] Where it was felt that the prone position contributed to the event the cases are discussed below.

There are four case reports of fat embolism in patients undergoing spinal surgery in the prone position but in only one[20] was it suggested that prolonged venous stasis in the prone position contributed to the release of multiple microemboli from bone harvesting sites. This patient also had spinal instrumentation, although the authors did not feel that this was the cause of the fat emboli. One case report describes pulmonary bone fragment embolism.[68] The patient underwent resection of an ossified posterior longitudinal ligament on a Hastings frame and suffered a cardiac arrest after 5 h of surgery. Resuscitation was unsuccessful and post-mortem examination revealed microscopic bone fragment emboli in the pulmonary capillary vasculature of all lung segments.

Practical procedures

Practical procedures which are relatively straightforward or familiar in the supine patient become more complex in the prone position. We have reviewed the literature on

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Table 2 VGE in the prone position

Surgical region	Year of publication (single cases unless otherwise stated)	Clinical features	Outcome
Cranial	1969[170]	Hypotension	Fatal
	1974:[124] review of 107 patients; two VGE episodes	Hypertension; murmur; arrhythmias	Frequency of embolism 1.7%
	1993[112]	Asystole	Non-fatal
	1994[137]	Tension pneumocephalus; increase in E'_{CO_2}/Pa_{O_2} gradient	Non-fatal
	1995:[90] two episodes in one patient	Asystole; bradycardia; hypotension	Non-fatal
	2000[46]	Decrease in E'_{CO_2}; hypotension; bradycardia; desaturation; froth aspirated from central venous catheter	Non-fatal
	2001[195]	Decrease in E'_{CO_2}; hypotension; increase in CVP; air aspirated from central venous catheter	Non-fatal
Spinal	1978[5]	Detected with Doppler monitoring; air aspirated from right atrial catheter	Non-fatal
	1988[51]	Hypotension, bradycardia; decrease in E'_{CO_2}; increase in nitrogen on mass spectrometry	Non-fatal
	1989[99]	Cardiovascular instability	Fatal
	1990:[122] two cases	Air bubbles at operative site; cardiac arrest	Fatal
	1991:[6] three cases	Hypotension; bradycardia; Millwheel murmur; ECG changes; decrease in E'_{CO_2}; asystole; air aspirated from central venous catheter (one case)	One non-fatal; two fatal
	1992:[76] two cases	Hypotension; arrhythmia; air bubbles at operative site; air aspirated from central venous catheter (one case)	One fatal; one non-fatal
	1992:[38] three cases	Decrease in E'_{CO_2}; tachycardia; ECG changes; bronchospasm; millwheel murmur	Non-fatal
	1997:[185] two cases	Loss of SSEP; decrease in E'_{CO_2}; asystole; air palpated in heart via thoracotomy (one case)	Both fatal
	1997[39]	Decrease in E'_{CO_2}; hypotension; desaturation; ST segment elevation	Non-fatal
	1999[113]	Decrease in E'_{CO_2}; hypotension; bradycardia; desaturation	Fatal
	2000:[135] four patients (part of larger blood transfusion study)		Non-fatal
	2001[22]	Decrease in E'_{CO_2}; hypotension; pulseless ventricular tachycardia	Non-fatal
	2002[147]	Decrease in E'_{CO_2}; hypertension; loss of evoked potentials; focal neurology after operation	Non-fatal; paraplegia
	2005:[219] two cases	Air bubbles at operative site; loss of evoked potentials; cardiovascular collapse	One fatal; one non-fatal
	2007[123]	Increase in HR; decrease in E'_{CO_2}; unrecordable BP	Fatal
Cranial and spinal	1990[61]	Decrease in Pa_{O_2} and increase in Pa_{O_2}; decrease in E'_{CO_2}	Non-fatal
Nephrolithotripsy	2002[44]	Decrease in E'_{CO_2}; hypotension; bradycardia; desaturation	Non-fatal; blindness and neurologic deficit after surgery

procedures and equipment used in the prone position, including how interventions have been modified for this position and procedure-related complications related to the position.

Airway management

The anaesthetist is trained to anticipate and plan for the worst-case scenario in all situations. Where the patient is to be positioned prone, this includes the risk of airway loss and for this reason, the favoured airway has classically been a tracheal tube, usually reinforced, secured to minimize the risk of accidental extubation.

A variety of problems with the tracheal tube may occur while a patient is prone. One report describes repeated obstruction of a tracheal tube after prone positioning as a result of bloody secretions draining under gravity from the right lower lobe.[109] This was resolved initially by turning the patient supine and subsequently by suction of the tube while the patient remained in the prone position. A case report of a tube obstructed by inspissated sputum plugs describes the use of an arterial embolectomy catheter to

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remove the plugs by inflating the catheter balloon beyond the plug and withdrawing the catheter on three occasions intraoperatively while the patient remained prone.[62]

Alternative airway management has also been described, usually the use of the laryngeal mask airway (LMA[†]) either as a primary adjunct or as a rescue measure in the event of difficulty.[21] Use of the LMA as a primary adjunct is controversial,[202] but it has been used effectively. The LMA has been placed after prone positioning, having requested the patient to position themselves awake.[217] This may avoid other adverse events related to the prone position such as soft tissue and nerve injury or spinal destabilization, but runs the risk of inability to maintain an adequate airway once anaesthesia has been induced. In one patient with a stenosed 'sabre-sheath' trachea, the LMA was used with a tracheal tube and an airway exchange catheter, as a backup route for ventilation and possible reintubation in the event of accidental extubation.[14]

In some patients, the airway may be more easily managed with the patient prone and may be more protected from regurgitation.[166] In almost all patients, the tongue will fall forward in this position and consequently the airway will tend to remain open. In most, the advantage is small as there is no difficulty in airway maintenance in the supine position. In some, for example, Pierre Robin syndrome, the improvement may be more significant as in a case report where the trachea was intubated nasally, blind, in the prone position.[149]

In other patients, trauma may necessitate airway management in the prone position. An adult with facial trauma who presented awake and prone because of a threatened airway successfully underwent awake fibreoptic intubation prone.[134] A patient who presented prone to the emergency department with a drill bit protruding from his neck, the tip of which was in the spinal canal was managed with manual inline stabilization, an inhalation induction, and placement of an LMA through which he was ventilated without the use of neuromuscular blocking drugs.[203] A similar episode has been reported.[110]

Cardiovascular procedures

Many of the procedures described which relate to the cardiovascular system involve the cannulation of various vessels in the intensive care setting. In the operating theatre, central venous catheterization prone has been described.[184] A central venous catheter sited with the patient supine,[164] but complicated by carotid puncture, led to airway compromise by a large haematoma which had developed unobserved after the patient was turned prone. The authors' conclusions were that where such a recognized arterial puncture occurs, the time period for direct pressure over the area should be extended and the repositioning of the patient should be postponed.

Cardiovascular monitoring and intervention using ultrasonographic techniques have also been examined. Transoesophageal echocardiography was carried out successfully in 12 patients undergoing scoliosis surgery to compare data from echocardiography with CVP monitoring.[178] It was felt to be a useful adjunct in assessing cardiovascular status in the patient with complex disease. A prospective study investigated transoesophageal atrial pacing and concluded that this technique can be performed effectively and safely in the prone position.[168] External Doppler probe placement for the detection of air embolism with posterior placement between right scapula and spine was effective in monitoring infants weighing under 10 kg, and more accessible and less traumatic than the standard anterior probe placement when the patient is prone.[179] Oesophageal echocardiography has enabled early detection of circulatory arrest and prompt management.[64]

There are several reports on the management of cardiac arrest in the prone patient. Conventional teaching has been that on the occurrence of a life-threatening adverse event, the patient should be returned to the supine position and this clearly has advantages in terms of access to the airway and praecordium, and familiarity. The routine use of two tables in the operating theatre, one to be available for the immediate supination of the unstable patient has been suggested. In some scenarios, however, this will not be possible; for example, when there are bulky surgical instruments protruding from the back as part of the operative procedure,[196] and hence the delay in repositioning may be substantial. In such situations, other techniques have been used with some success. Chest compressions have been delivered successfully with the hands on the central upper back, between the scapulae. In some patients, it has been found necessary to provide counter-pressure between the chest and the operating table to effectively compress the thoracic cage. Both one-handed and two-handed manoeuvres have been described, as have a variety of hand positions to avoid open operative sites. The success of this technique supports the theory that the mechanism of closed chest massage involves a 'thoracic pump' process rather than direct cardiac compression.[196] In one patient with an unstable spine, internal cardiac massage was undertaken via a left thoracotomy incision.[156] A 'postcordial' thump delivered between the shoulderblades to treat pulseless ventricular tachycardia has also been described.[130]

Defibrillation has been successfully undertaken using the anterior–posterior paddle position,[24] or paddle orientation on left and right sides of the back.[126] However, the use of posterior paddle positions may not deliver energy to sufficient myocardium, owing to anterior displacement of the heart in the prone position and also increased transthoracic impedance with positive pressure ventilation.[209] The authors recommend the use of biphasic shocks and anterior paddle or pad positioning. It has also been recommended that self-adhesive pads be placed before

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prone positioning of the high-risk patient.[156] Rarely, the prone position may even benefit the patient needing resuscitation where mediastinal masses compress the trachea or obstruct cardiac filling in the supine position.[108]

Conclusion

We have described the historical development of the prone position and its variants, with their advantages and disadvantages. It is clear that the specific prone position and support system used influences not only the incidence of complications but also the alterations in cardiovascular and respiratory physiology which occur when a patient is moved from supine to prone position in the operating theatre. The prone position is associated with a variety of complications, some of which may be prevented with care on the part of the anaesthetist. It is also apparent that many airway-related or cardiovascular procedures can be undertaken in the prone position, although whether they should be is more controversial.

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