



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.

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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, Ecker⁴⁷ 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 patients¹⁶ 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 laminectomy¹⁹⁹ 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 monitoring²²⁶ demonstrated that the flat prone position did not interfere with circulatory function but that positioning

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’ position¹⁷⁵ 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 Frame¹⁵⁵ 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 Tarlov¹⁹⁰ 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’ position⁹⁴ 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 |
| ‘Mohammedan Prayer’ ¹¹¹ | Chest supported in sling Arms crossed in front of face As for ‘Kneeling’, but: chest supported with pillows Arms abducted at shoulder above head Head-up tilt | Flexion of spine Reduced tension on nerve roots Reduced intra-abdominal pressure | Risk of crush injury as above |
| Moore and Edmunds Frame ¹²⁹ | Patient suspended between longitudinal bars of curved frame | Flexion of spine Reduced intra-abdominal pressure | Increased tension in paraspinal muscles Manual handling issues Pressure injury |
| Overholt position ⁴⁹ | Crest of ilium supported by edge of table. Adjustable pad under upper third of sternum. Head in headrest | Portable Cheap Free chest expansion allows spontaneous respiration during thoracic surgery | |
| Mackay Frame ¹¹⁷ | Two longitudinal curved bolsters Patient supported on iliac crests and mid-clavicles | Adjustable curvature for any degree of flexion/extension Cheap and robust | |
| ‘Prone Jack Knife’ ¹⁹¹ | Arms extended above head* Pelvis supported (weight borne on anterior pelvis and sternum) Knees semi-flexed Thighs flexed to 45° Arms abducted at shoulders | Reduced intra-abdominal pressure Much reduced intra-abdominal pressure | Does not undo lumbar lordosis (poor surgical access to spine) Risk of femoral vessel injury |
| ‘Georgia Prone’ ^{†,‡ 177} | Kneeling on shelf, hips flexed at 90°; weight borne on knees Pelvis supported under iliac crests Pillows under chest Arms abducted above head | Patient comfort (derived from experiments on awake subjects) Good surgical access (thigh flexion flattens lumbar spine) | Manual handling issues All weight borne by knees Increased CVP Tight paraspinal muscles can limit lateral surgical access |
| Relton and Hall Frame ¹⁵⁷ | Head turned to side Four individually adjustable supports in two V-shaped pairs tilting inwards at 45° Supports lateral thoracic cage and antero-lateral pelvis | Reduced intra-abdominal pressure Tends to correct scoliosis Adjustable for any body habitus and degree of scoliosis Very stable Can be modified to allow skeletal traction ¹³¹ | Increases lumbar lordosis (unsuitable for disc surgery) |
| ‘Seated Prone’ ^{*,§ 190} | Weight supported on ischial tuberosities 45° head-up tilt making back horizontal Chest padded | Very low venous pressures ³² Weight borne on ischii, not knees Reduced risk of crush injury and deep venous thrombosis | Theoretical risk of venous air embolus (because of low venous pressures) Unstable position Tight paraspinal muscles can limit lateral surgical access |
| ‘Tuck’ position ²¹⁴ | Head rotated Arms abducted above head Very similar to ‘Prayer’ position Hips flexed >90° | Low venous pressures Spinal flexion improves surgical access | Risk of crush injury and deep venous thrombosis Tight paraspinal muscles can limit lateral surgical access |
| Hastings Frame ⁶⁹ | Head-down tilt As for ‘Seated prone’ Wooden frame with adjustable seat | Fewer manual handling problems More stable than ‘Seated prone’ Degree of spinal flexion variable | Venous pooling in legs |

Continued

Table 1 (*Continued*)

| Variation | Description | Advantages | Disadvantages |
|-------------------------------------|--|--|--|
| Smith Frame ¹⁷⁶ | Two curved supports under iliac crests Pile of folded sheets under chest | 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} | Neck flexed and rotated 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 | |
| Evacuatable Mattress ¹⁸³ | Airtight flexible mattress Becomes rigid on evacuation. Moulded around patient to support iliac crests and thorax but with abdomen free | Risk of crush injury and deep venous thrombosis low 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 study²⁰⁷ 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 baroreceptor 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 study¹⁴² 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 study¹⁸² 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 H₂O in one patient. The position resulting in the

least compression (changes of up to 4 cm H₂O) 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 Hope³³ 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 (P_{aO_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 P_{aO_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 movement¹¹⁶ 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 study¹¹⁸ 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

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 1960s⁸⁷ 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 studies⁸⁷ 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. One¹⁰⁰ 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 infarcts¹⁹³ 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 quadriplegia, and one paraparesis).¹⁸ In each patient, the cause was not apparent; any arterial

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 quadriplegia³⁷ 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 achondroplasia⁴⁸ 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 colleagues¹⁹⁸ 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 report¹⁵¹ 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 Parks¹⁴³ 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

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 first⁹⁵ 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 second²⁷ 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 limbs⁸⁵ 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 surgery⁶⁵ attributed this to the arms being abducted above the head. Musculocutaneous³ 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 injury¹²⁰ 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 reports¹⁴³ 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 nerve²⁰⁸ 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 possible²²⁰ 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

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 face⁸² 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 rotated⁶⁷ 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. One¹⁴⁸ 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

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 oximetry¹⁷³ or radial artery monitoring⁹ on the affected arm. In a patient²⁰⁶ 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 study³⁶ 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

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 lens⁹³ and fixed mydriasis.²³ Studies have been conducted examining keratoconjunctival injury¹⁹ and postoperative chemosis⁸¹ 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 examination¹⁰² 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 review¹⁰² 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

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 occlusion¹⁸⁸ 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 H₂O.⁴³ This negative pressure could then move gas along the gradient of 10–15 cm H₂O 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 one²⁰ 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

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 |
| Spinal | 2001 ¹⁹⁵ | Decrease in E'_{CO_2} ; hypotension; increase in CVP; air aspirated from central venous catheter | Non-fatal |
| | 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

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 fiberoptic 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 'post-cordial' 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 trans-thoracic 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

[†]LMA[®] is the property of Intavent Ltd.

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.

References

- Practice Advisory for perioperative visual loss associated with spine surgery: a report by the American Society of Anesthesiologists Task Force on perioperative blindness. *Anesthesiology* 2006; **104**: 1319–28
- Practice advisory for the prevention of perioperative peripheral neuropathies: a report by the American Society of Anesthesiologists Task Force on Prevention of Perioperative Peripheral Neuropathies. *Anesthesiology* 2000; **92**: 1168–82
- Abbott KM, Nesathurai S. Musculocutaneous nerve palsy following traumatic spinal cord injury. *Spinal Cord* 1998; **36**: 588–90
- Akagi S, Yoshida Y, Kato I, *et al.* External iliac artery occlusion in posterior spinal surgery. *Spine* 1999; **24**: 823–5
- Albin MS, Carroll RG, Maroon JC. Clinical considerations concerning detection of venous air embolism. *Neurosurgery* 1978; **3**: 380–4
- Albin MS, Ritter RR, Pruett CE, Kalff K. Venous air embolism during lumbar laminectomy in the prone position: report of three cases. *Anesth Analg* 1991; **73**: 346–9
- Albin MS, Ritter R, Sloan T, Hickey R, Bunegin L. Central registry for venous air embolism. *Anesth Analg* 1995; **81**: 658
- Alexianu D, Skolnick ET, Pinto AC, *et al.* Severe hypotension in the prone position in a child with neurofibromatosis, scoliosis and pectus excavatum presenting for posterior spinal fusion. *Anesth Analg* 2004; **98**: 334–5
- Ali AA, Breslin DS, Hardman HD, Martin G. Unusual presentation and complication of the prone position for spinal surgery. *J Clin Anesth* 2003; **15**: 471–3
- Amis TC, Jones HA, Hughes JM. Effect of posture on inter-regional distribution of pulmonary ventilation in man. *Respir Physiol* 1984; **56**: 145–67
- Anand S, Mushin AS. Cavernous sinus thrombosis following prone position anaesthesia. *Eye* 2005; **19**: 803–4
- Anderton JM. The prone position for the surgical patient: a historical review of the principles and hazards. *Br J Anaesth* 1991; **67**: 452–63
- Anderton JM, Schady W, Markham DE. An unusual cause of post-operative brachial plexus palsy. *Br J Anaesth* 1994; **72**: 605–7
- Asai T, Shingu K. Airway management of a patient with tracheal stenosis for surgery in the prone position. *Can J Anaesth* 2004; **51**: 733–6
- Aschoff A, Steiner-Milz H, Steiner HH. Lower limb compartment syndrome following lumbar discectomy in the knee–chest position. *Neurosurg Rev* 1990; **13**: 155–9
- Backofen JE SJ. Hemodynamic changes with prone positioning during general anesthesia. *Anesth Analg* 1985; **64**: 194
- Bagshaw ON, Jardine A. Cardiopulmonary complications during anaesthesia and surgery for severe thoracic lordoscoliosis. *Anaesthesia* 1995; **50**: 890–2
- Bhardwaj A, Long DM, Ducker TB, Toung TJ. Neurologic deficits after cervical laminectomy in the prone position. *J Neurosurg Anesthesiol* 2001; **13**: 314–9
- Biswas BK, Bithal PK, Dash M, Lamba NS, Biswas N. Keratoconjunctival injury in the prone position: a prospective study in neurosurgical patients. *Eur J Anaesthesiol* 2004; **21**: 663–5
- Brandt SE, Zeegers WS, Ceelen TL. Fatal pulmonary fat embolism after dorsal spinal fusion. *Eur Spine J* 1998; **7**: 426–8
- Brimacombe J, Keller C. An unusual case of airway rescue in the prone position with the ProSeal laryngeal mask airway. *Can J Anaesth* 2005; **52**: 884
- Brown J, Rogers J, Soar J. Cardiac arrest during surgery and ventilation in the prone position: a case report and systematic review. *Resuscitation* 2001; **50**: 233–8
- Caricato A, Pennisi MA, Pappalardo F, Iodice F, Lepore D. Bilateral fixed mydriasis reversible during orthopedic surgery in the prone position. *Anesthesiology* 1999; **90**: 1777–8
- Cattell E, Saravanan P, Chay S, Lawler PG. The defibrillator back paddle: use for treatment of arrhythmias during prone position ventilation. *Anaesthesia* 2000; **55**: 491
- Chandra PS, Jaiswal A, Mahapatra AK. Bifrontal epidural haematoma following surgery for occipital falcine meningioma: an unusual complication of surgery in the prone position. *J Clin Neurosci* 2002; **9**: 582–4
- Chen S-H, Hui Y-L, Yu C-M, Niu C-C, Lui P-W. Paraplegia by acute cervical disc protrusion after lumbar spine surgery. *Chang Gung Med J* 2005; **28**: 254–7
- Cheney FW, Domino KB, Caplan RA, Posner KL. Nerve injury associated with anesthesia: a closed claims analysis. *Anesthesiology* 1999; **90**: 1062–9
- Cheng MA, Sigurdson W, Tempelhoff R, Laurysen C. Visual loss after spine surgery: a survey. *Neurosurgery* 2000; **46**: 625–30; discussion 30–1
- Cheng MA, Tempelhoff R. Postoperative visual loss, still no answers yet [comment]. *Anesthesiology* 2002; **96**: 1531
- Cheng MA, Todorov A, Tempelhoff R, McHugh T, Crowder CM, Laurysen C. The effect of prone positioning on intraocular pressure in anesthetized patients [see comment]. *Anesthesiology* 2001; **95**: 1351–5
- Chu Y-C, Tsai S-K, Chan K-H, Kao S-C, Liang C-H, Lin S-M. Lateral medullary syndrome after prone position for general surgery. *Anesth Analg* 2002; **95**: 1451–3
- Cook AW, Siddiqi TS, Nidzgorski F, Clarke HA. Sitting prone position for the posterior surgical approach to the spine and posterior fossa. *Neurosurgery* 1982; **10**: 232–5
- Coonan TJ, Hope CE. Cardio-respiratory effects of change of body position. *Can Anaesth Soc* 1983; **30**: 424–37
- Cruette D, Navarre MC, Pinaquy C, Simeon F. Rhabdomyolysis after prolonged knee–chest position. *Ann Fr Anesth Reanim* 1986; **5**: 67–9

- 35 Curtin WA, Lahoti OP, Fogarty EE, Dowling FE, Regan BF, Drumm B. Pancreatitis after alar-transverse fusion for spondylolisthesis. A case report. *Clin Orthop* 1993; 142–3
- 36 Davidas JL, Roullit S, Dubost J, et al. Creatine phosphokinases and serum and urinary myoglobin following a procedure in prolonged knee-chest position for the treatment of spondylolisthesis. *Ann Fr Anesth Reanim* 1986; 5: 31–4
- 37 Deem S, Shapiro HM, Marshall LF. Quadriplegia in a patient with cervical spondylosis after thoracolumbar surgery in the prone position. *Anesthesiology* 1991; 75: 527–8
- 38 Delaloye D, Gerber H. A special surgical technique leads to venous air embolism during neurosurgery of the spine [comment]. *Anesth Analg* 1992; 75: 468–9
- 39 Despond O, Fiset P. Oxygen venous embolism after the use of hydrogen peroxide during lumbar discectomy. *Can J Anaesth* 1997; 44: 410–3
- 40 Dhuner K. Nerve injuries following operations: a survey of cases occurring during a six year period. *Anesthesiology* 1950; 11: 289–93
- 41 Dilger JA, Tetzlaff JE, Bell GR, Kosmorsky GS, Agnor RC, O'Hara JF, Jr. Ischaemic optic neuropathy after spinal fusion. *Can J Anaesth* 1998; 45: 63–6
- 42 Dinmore P. A new operating position for posterior spinal surgery. *Anaesthesia* 1977; 32: 377–80
- 43 DiStefano VJ, Klein KS, Nixon JE, Andrews ET. Intra-operative analysis of the effects of position and body habitus on surgery of the low back. A preliminary report. *Clin Orthop* 1974; 99: 51–6
- 44 Droghetti L, Giganti M, Memmo A, Zatelli R. Air embolism: diagnosis with single-photon emission tomography and successful hyperbaric oxygen therapy. *Br J Anaesth* 2002; 89: 775–8
- 45 Drummond JC. Macroglossia, déjà vu [comment]. *Anesth Analg* 1999; 89: 534–5
- 46 Dubey PK, Singh AK. Venous oxygen embolism due to hydrogen peroxide irrigation during posterior fossa surgery. *J Neurosurg Anesthesiol* 2000; 12: 54–6
- 47 Ecker A. Kneeling position for operations on the lumbar spine. *Surgery* 1949; 25: 112
- 48 Elmaci I, Ain MC, Wright MJ, et al. Perioperative intracranial hemorrhage in achondroplasia: a case report [erratum appears in *J Neurosurg Anesthesiol* 2001; 13(1): 59]. *J Neurosurg Anesthesiol* 2000; 12: 217–20
- 49 Etsten BE. Respiratory acidosis during intrathoracic surgery; the Overholt prone position. *J Thorac Surg* 1953; 25: 286–99
- 50 Foster MR. Rhabdomyolysis in lumbar spine surgery: a case report. *Spine* 2003; 28: E276–8
- 51 Frankel AS, Holzman RS. Air embolism during posterior spinal fusion. *Can J Anaesth* 1988; 35: 511–4
- 52 Galvin I, Drummond GB, Nirmalan M. Distribution of blood flow and ventilation in the lung: gravity is not the only factor. *Br J Anaesth* 2007; 98: 420–8
- 53 Geisler FH, Laich DT, Goldflies M, Shepard A. Anterior tibial compartment syndrome as a positioning complication of the prone-sitting position for lumbar surgery. *Neurosurgery* 1993; 33: 1117
- 54 Gercek A, Konya D, Babayev R, Ozgen S. Delayed recovery from general anesthesia from intracranial tumor. *Anesth Analg* 2007; 104: 235–6
- 55 Glenn RW LV, Albert RK, Robertson HT. Gravity is a minor determinant of pulmonary blood flow distribution. *J Appl Physiol* 1991; 71: 620–9
- 56 Goettler CE, Pryor JP, Reilly PM. Brachial plexopathy after prone positioning. *Crit Care* 2002; 6: 540–2
- 57 Gordon B, Newman W. Lower nephron syndrome following prolonged knee–chest position. *JBS (Am)* 1953; 35A: 764–8
- 58 Gordon-Bennett P, Ung T, Stephenson C, Hingorani M. Misdiagnosis of angle closure glaucoma. *Br Med J* 2006; 333: 1157–8
- 59 Gould DB, Cunningham K. Internal carotid artery dissection after remote surgery. Iatrogenic complications of anesthesia. *Stroke* 1994; 25: 1276–8
- 60 Greenberg R, Tymms A. Alert for perioperative visual loss: an unusual presentation of an orbital haemangioma during spinal surgery. *Anaesth Intensive Care* 2003; 31: 679–82
- 61 Greenblatt G, Barker SJ, Tremper KK, Gerschultz S, Gehrich JL. Detection of venous air embolism by continuous intraarterial oxygen monitoring. *J Clin Monit* 1990; 6: 53–6
- 62 Grimmer WG, Poh J. Clearance of an obstructed endotracheal tube with an arterial embolectomy catheter with the patient in the prone position. *Anaesth Intensive Care* 1998; 26: 579–81
- 63 Grossman W, Ward WT. Central retinal artery occlusion after scoliosis surgery with a horseshoe headrest. Case report and literature review. *Spine* 1993; 18: 1226–8
- 64 Gueugniaud PY, Muchada R, Bertin-Maghit M, Griffith N, Petit P. Non-invasive continuous haemodynamic and PETCO₂ monitoring during peroperative cardiac arrest. *Can J Anaesth* 1995; 42: 910–3
- 65 Gwinnett CL. Injury to the axillary nerve [erratum appears in *Anaesthesia* 1988; 43(6): 529]. *Anaesthesia* 1988; 43: 205–6
- 66 Halfon MJ, Bonardo P, Valensi S, et al. Central retinal artery occlusion and ophthalmoplegia following spinal surgery. *Br J Ophthalmol* 2004; 88: 1350–2
- 67 Hans P, Demoitie J, Collignon L, Bex V, Bonhomme V. Acute bilateral submandibular swelling following surgery in prone position. *Eur J Anaesthesiol* 2006; 23: 83–4
- 68 Hara N, Minami T. Diffusive pulmonary embolism with bone fragments during spinal surgery. *Br J Anaesth* 2006; 97: 119–20
- 69 Hastings DE. A simple frame for operations on the lumbar spine. *Can J Surg* 1969; 12: 251–3
- 70 Hatada T, Kusunoki M, Sakiyama T, et al. Hemodynamics in the prone jackknife position during surgery. *Am J Surg* 1991; 162: 55–8
- 71 Hinton AE, King D. Anterior shoulder dislocation as a complication of surgery for burns. *Burns* 1989; 15: 248–9
- 72 Hiraga Y, Maruoka H, Yamamoto M, et al. Compression of the graft during the corrective surgery for scoliosis in a patient who has undergone a Rastelli's operation: a case study. *Masui* 1992; 41: 1490–3
- 73 Ho VTG, Newman NJ, Song S, Ksiazek S, Roth S. Ischemic optic neuropathy following spine surgery. *J Neurosurg Anesthesiol* 2005; 17: 38–44
- 74 Hofmann A, Jones RE, Schoenvogel R. Pudendal-nerve neuropathy as a result of traction on the fracture table. A report of four cases. *J Bone Joint Surg Am* 1982; 64: 136–8
- 75 Hollenhorst R, Svien HJ, Benoit CF. Unilateral blindness occurring during anesthesia for neurosurgical operations. *AMA Arch Ophthalmol* 1954; 52: 819–30
- 76 Horlocker TT, Wedel DJ, Cucchiara RF. Venous air embolism during spinal instrumentation and fusion in the prone position [comment]. *Anesth Analg* 1992; 75: 152; author reply 3
- 77 Hunt K, Bajekal R, Calder I, Meacher R, Eliahoo J, Acheson JF. Changes in intraocular pressure in anesthetized prone patients. *J Neurosurg Anesthesiol* 2004; 16: 287–90
- 78 Iwabuchi T, Ishii M, Julow J. Biparieto-occipital craniotomy with hyperextended neck—'sea lion' position. *Acta Neurochir (Wien)* 1979; 51: 113–7

- 79 Jackson L, Keats AS. Mechanism of brachial plexus palsy following anesthesia. *Anesthesiology* 1965; **26**: 190–4
- 80 Jain V, Bithal PK, Rath GP. Pressure sore on malar prominences by horseshoe headrest in prone position. *Anaesth Intensive Care* 2007; **35**: 304–5
- 81 Jeon YT, Park YO, won Hwang J, Lim YJ, Oh YS, Park HP. Effect of head position on postoperative chemosis after prone spinal surgery. *J Neurosurg Anesthesiol* 2007; **19**: 1–4
- 82 Jericho BG, Skaria GP. Contact dermatitis after the use of the PronePositioner. *Anesth Analg* 2003; **97**: 1706–8
- 83 Jones AT HD, Evans TW. Pulmonary perfusion in supine and prone positions: an electron-beam computed tomography study. *J Appl Physiol* 2001; **90**: 1342–8
- 84 Kai Y, Yamaoka A, Irita K, Zaitzu A, Takahashi S. Transient tracheal obstruction during surgical correction of scoliosis in a patient with Marfan's syndrome. *Masui* 1995; **44**: 868–73
- 85 Kamel IR, Drum ET, Koch SA, et al. The use of somatosensory evoked potentials to determine the relationship between patient positioning and impending upper extremity nerve injury during spine surgery: a retrospective analysis. *Anesth Analg* 2006; **102**: 1538–42
- 86 Kamming D, Clarke S. Postoperative visual loss following prone spinal surgery [see comment]. *Br J Anaesth* 2005; **95**: 257–60
- 87 Kaneko K, Milic-Emili J, Dolovich MB, Dawson A, Bates DV. Regional distribution of ventilation and perfusion as a function of body position. *J Appl Physiol* 1966; **21**: 767–77
- 88 Katzman SS, Moschonas CG, Dzioba RB. Amaurosis secondary to massive blood loss after lumbar spine surgery. *Spine* 1994; **19**: 468–9
- 89 Keim HA, Weinstein JD. Acute renal failure—a complication of spine fusion in the tuck position. A case report. *J Bone Joint Surg Am* 1970; **52**: 1248–50
- 90 Kelleher A, Mackersie A. Cardiac arrest and resuscitation of a 6-month old achondroplastic baby undergoing neurosurgery in the prone position. *Anaesthesia* 1995; **50**: 348–50
- 91 Kim C, Blank J, McClain BC. Transient paraparesis after general anesthesia in a patient in the prone position. *Anesthesiology* 1994; **81**: 775–7
- 92 Kimura H, Watanabe Y, Mizukoshi K, Yamamoto Y, Araki S. Six cases of anesthesia mumps. *Nippon Jibiinkoka Gakkai Kaiho* 1993; **96**: 1915–21
- 93 Kiran S, Gombar S, Chhabra B, Gombar K. Another hazard of the prone position. *Anesth Analg* 1997; **85**: 949
- 94 Kobayashi S, Sugita K, Tanaka Y, Kyoshima K. Infratentorial approach to the pineal region in the prone position: concorde position. Technical note. *J Neurosurg* 1983; **58**: 141–3
- 95 Kroll DA, Caplan RA, Posner K, Ward RJ, Cheney FW. Nerve injury associated with anesthesia [see comment]. *Anesthesiology* 1990; **73**: 202–7
- 96 Kumar N, Jivan S, Topping N, Morrell AJ. Blindness and rectus muscle damage following spinal surgery. *Am J Ophthalmol* 2004; **138**: 889–91
- 97 Kuperwasser B, Zaid BT, Ortega R. Compartment syndrome after spinal surgery and use of the Codman frame. *Anesthesiology* 1995; **82**: 793
- 98 Laakso E, Ahovuo J, Rosenberg PH. Blood flow in the lower limbs in the knee–chest position. Ultrasonographic study in unanaesthetised volunteers. *Anaesthesia* 1996; **51**: 1113–6
- 99 Lang SA, Duncan PG, Dupuis PR. Fatal air embolism in an adolescent with Duchenne muscular dystrophy during Harrington instrumentation. *Anesth Analg* 1989; **69**: 132–4
- 100 Langmayr JJ, Ortler M, Obwegeser A, Felber S. Quadriplegia after lumbar disc surgery. A case report [see comment]. *Spine* 1996; **21**: 1932–5
- 101 Laurin CA, Migneault G, Brunet JL, Roy P. Knee–chest support for lumbosacral operations. *Can J Surg* 1969; **12**: 245–50
- 102 Lee L, Roth MD, Posner KL, et al. The American Society of Anesthesiologists Postoperative visual loss registry: analysis of 93 spine surgery cases with postoperative visual loss. *Anesthesiology* 2006; **105**: 652–9
- 103 Lee LA. ASA Postoperative visual loss registry: preliminary analysis of factors associated with spine operations. *ASA Newsletter* 2003; **67**: 7–8
- 104 Lee LA, Lam AM. Unilateral blindness after prone lumbar spine surgery [see comment]. *Anesthesiology* 2001; **95**: 793–5
- 105 Lee TC, Yang LC, Chen HJ. Effect of patient position and hypotensive anesthesia on inferior vena caval pressure. *Spine* 1998; **23**: 941–7; discussion 7–8
- 106 Leibovitch I, Casson R, Laforest C, Selva D. Ischemic orbital compartment syndrome as a complication of spinal surgery in the prone position [see comment]. *Ophthalmology* 2006; **113**: 105–8
- 107 Lesser RP, Raudzens P, Luders H, et al. Postoperative neurological deficits may occur despite unchanged intraoperative somatosensory evoked potentials. *Ann Neurol* 1986; **19**: 22–5
- 108 Levin H, Bursztein S, Heifetz M. Cardiac arrest in a child with an anterior mediastinal mass. *Anesth Analg* 1985; **64**: 1129–30
- 109 Lin J-A, Wong C-S, Chheng C-H. Unexpected blood clot-induced acute airway obstruction in a patient with inactive pulmonary tuberculosis during lumbar spine surgery in the prone position—a case report. *Acta Anaesthesiol Taiwan* 2005; **43**: 93–7
- 110 Lipp M, Mihaljevic V, Jakob H, Mildenerberger P, Rudig L, Dick W. Fiberoptic intubation in the prone position. Anesthesia in a thoraco-abdominal knife stab wound. *Anaesthesist* 1993; **42**: 305–8
- 111 Lipton S. Anaesthesia in the surgery of retropulsed vertebral discs. *Anaesthesia* 1950; **5**: 208–12
- 112 Loewenthal A, De Albuquerque AM, Lehmann-Meurice C, Otteni JC. Efficacy of external cardiac massage in a patient in the prone position. *Ann Fr Anesth Reanim* 1993; **12**: 587–9
- 113 Lopez LM, Traves N, Napal M. Fatal gas embolism during corrective surgery for scoliosis using the posterior approach. *Rev Esp Anesthesiol Reanim* 1999; **46**: 267–70
- 114 Lorenzini NA, Poterack KA. Somatosensory evoked potentials are not a sensitive indicator of potential positioning injury in the prone patient. *J Clin Monit* 1996; **12**: 171–6
- 115 Lumb AB, Nunn JF. Respiratory function and ribcage contribution to ventilation in body positions commonly used during anesthesia. *Anesth Analg* 1991; **73**: 422–6
- 116 Lynch S, Brand L, Levy A. Changes in lung–thorax compliance during orthopedic surgery. *Anesthesiology* 1959; **20**: 278–82
- 117 Mackay I. A new frame for the positioning of patients for surgery of the back. *Can Anaesth Soc J* 1956; **3**: 279–82
- 118 Mahajan RP, Hennessy N, Aitkinhead AR, Jellinek D. Effect of three different surgical prone positions on lung volumes in healthy volunteers. *Anaesthesia* 1994; **49**: 583–6
- 119 Mahla ME, Long DM, McKennett J, Green C, McPherson RW. Detection of brachial plexus dysfunction by somatosensory evoked potential monitoring—a report of two cases. *Anesthesiology* 1984; **60**: 248–52
- 120 Massey EV, Pleet AB. Compression injury of the sciatic nerve during a prolonged surgical procedure in a diabetic patient. *J Am Geriatr Soc* 1980; **28**: 188–9

- 121 Mayo JR, Mackay AL, Whittall KP, Kaile EM, Pare PD. Measurement of lung water content and pleural pressure gradient with magnetic resonance imaging. *J Thorac Imaging* 1995; **10**: 73–81
- 122 McCarthy RE, Lonstein JE, Mertz JD, Kuslich SD. Air embolism in spinal surgery. *J Spinal Disord* 1990; **3**: 1–5
- 123 McDouall SF, Shlugman D. Fatal venous air embolism during lumbar surgery: the tip of an iceberg? *Eur J Anaesthesiol* 2007; **24**: 803–16
- 124 Meridy HW, Creighton RE, Humphreys RP. Complications during neurosurgery in the prone position in children. *Can Anaesth Soc J* 1974; **21**: 445–53
- 125 Mesrobian RB, Epps JL. Midtracheal obstruction after Harrington rod placement in a patient with Marfan's syndrome. *Anesth Analg* 1986; **65**: 411–3
- 126 Miranda CC, Newton MC. Successful defibrillation in the prone position [see comment]. *Br J Anaesth* 2001; **87**: 937–8
- 127 Mirski MA, Lele AV, Fitzsimmons L, Toung TJK. Vascular air emboli. *Anesthesiology* 2007; **106**: 164–77
- 128 Monticelli F, Meyer HJ, Tutsch-Bauer E. Fatal pulmonary cement embolism following percutaneous vertebroplasty (PVP). *Forensic Sci Int* 2005; **149**: 35–8
- 129 Moore DC, Edmunds LH. Prone position frame. *Surgery* 1950; **27**: 276–9
- 130 Moore EW, Davies MW. A slap on the back. *Anaesthesia* 1999; **54**: 308
- 131 Mouradian WH, Simmons EH. A frame for spinal surgery to reduce intra-abdominal pressure while continuous traction is applied. *J Bone Joint Surg Am* 1977; **59**: 1098–9
- 132 Mutoh T, Guest RJ, Lamm WJ, Albert RK. Prone position alters the effect of volume overload on regional pleural pressures and improves hypoxemia in pigs in vivo. *Am Rev Respir Dis* 1992; **146**: 300–6
- 133 Myers MA, Hamilton SR, Bogosian AJ, Smith CH, Wagner TA. Visual loss as a complication of spine surgery. A review of 37 cases. *Spine* 1997; **22**: 1325–9
- 134 Neal MR, Groves J, Gell IR. Awake fiberoptic intubation in the semi-prone position following facial trauma. *Anaesthesia* 1996; **51**: 1053–4
- 135 Nuttall GA, Horlocker TT, Santrach PJ, Oliver WC, Jr, Dekutoski MB, Bryant S. Predictors of blood transfusions in spinal instrumentation and fusion surgery. *Spine* 2000; **25**: 596–601
- 136 Nyren S, Mure M, Jacobsson H, Larsson SA, Lindahl SGE. Pulmonary perfusion is more uniform in the prone than in the supine position: scintigraphy in healthy humans. *J Appl Physiol* 1999; **86**: 1135–41
- 137 Olympio MA, Bell WO. Venous air embolism after craniotomy closure: tension pneumocephalus implicated. *J Neurosurg Anesthesiol* 1994; **6**: 35–9
- 138 Ono S, Nishiyama T, Hanaoka K. Hoarseness after endotracheal intubation caused by submucosal hemorrhage of the vocal cord and recurrent nerve palsy. *Masui* 2000; **49**: 881–3
- 139 Orpen N, Walker G, Fairlie N, Coghill S, Birch N. Avascular necrosis of the femoral head after surgery for lumbar spinal stenosis. *Spine* 2003; **28**: E364–7
- 140 Owen CA, Mubarak SJ, Hargens AR, Rutherford L, Garetto LP, Akeson WH. Intramuscular pressures with limb compression clarification of the pathogenesis of the drug-induced muscle-compartment syndrome. *N Engl J Med* 1979; **300**: 1169–72
- 141 Ozcan MS, Praetel C, Bhatti MT, Gravenstein N, Mahla ME, Seubert CN. The effect of body inclination during prone positioning on intraocular pressure in awake volunteers: a comparison of two operating tables. *Anesth Analg* 2004; **99**: 1152–8
- 142 Ozkose Z, Ercan B, Unal Y, et al. Inhalation versus total intravenous anesthesia for lumbar disc herniation: comparison of hemodynamic effects, recovery characteristics, and cost. *J Neurosurg Anesthesiol* 2001; **13**: 296–302
- 143 Parks BJ. Postoperative peripheral neuropathies. *Surgery* 1973; **74**: 348–57
- 144 Pearce DJ. The role of posture in laminectomy. *Proc R Soc Med* 1957; **50**: 109–12
- 145 Pelosi P, Croci M, Calappi E, et al. The prone positioning during general anesthesia minimally affects respiratory mechanics while improving functional residual capacity and increasing oxygen tension. *Anesth Analg* 1995; **80**: 955–60
- 146 Pelosi P, Croci M, Calappi E, et al. Prone positioning improves pulmonary function in obese patients during general anesthesia. *Anesth Analg* 1996; **83**: 578–83
- 147 Pham Dang C, Pereon Y, Champin P, Delecun J, Passuti N. Paradoxical air embolism from patent foramen ovale in scoliosis surgery. *Spine* 2002; **27**: E291–5
- 148 Pivalizza EG, Katz J, Singh S, Liu W, McGraw-Wall BL. Massive macroglossia after posterior fossa surgery in the prone position. *J Neurosurg Anesthesiol* 1998; **10**: 34–6
- 149 Populaire C, Lundy JN, Pinaud M, Souron R. Elective tracheal intubation in the prone position for a neonate with Pierre Robin syndrome. *Anesthesiology* 1985; **62**: 214–5
- 150 Pousman RM, Eilers WA, 3rd, Johns B, Jung H. Irritant contact dermatitis after use of Bispectral Index sensor in prone position. *Anesth Analg* 2002; **95**: 1337–8
- 151 Prabhakar H, Bithal PK, Ghosh I, Dash HH. Pneumorrhachis presenting as quadriplegia following surgery in the prone position. *Br J Anaesth* 2006; **97**: 901–3
- 152 Prabhu M, Samra S. An unusual cause of rhabdomyolysis following surgery in the prone position. *J Neurosurg Anesthesiol* 2000; **12**: 359–63
- 153 Pump B, Talleruphuus U, Christensen NJ, Warberg J, Norsk P. Effects of supine, prone, and lateral positions on cardiovascular and renal variables in humans. *Am J Physiol Regul Integr Comp Physiol* 2002; **283**: R174–R80
- 154 Rau C-S, Liang C-L, Lui C-C, Lee T-C, Lu K. Quadriplegia in a patient who underwent posterior fossa surgery in the prone position. Case report. *J Neurosurg* 2002; **96**: 101–3
- 155 Ray CD. New kneeling attachment and cushioned face rest for spinal surgery. *Neurosurgery* 1987; **20**: 266–9
- 156 Reid JM, Appleton PJ. A case of ventricular fibrillation in the prone position during back stabilisation surgery in a boy with Duchenne's muscular dystrophy [see comment]. *Anaesthesia* 1999; **54**: 364–7
- 157 Relton JE, Hall JE. An operation frame for spinal fusion. A new apparatus designed to reduce haemorrhage during operation. *J Bone Joint Surg Br* 1967; **49**: 327–32
- 158 Rittoo DB, Morris P. Tracheal occlusion in the prone position in an intubated patient with Duchenne muscular dystrophy. *Anaesthesia* 1995; **50**: 719–21
- 159 Rodriguez-Nieto MJ, Peces-Barba G, Gonzalez Mangado N, Paiva M, Verbanck S. Similar ventilation distribution in normal subjects prone and supine during tidal breathing. *J Appl Physiol* 2002; **92**: 622–6
- 160 Roth S, Barach P. Postoperative visual loss: still no answers—yet [comment]. *Anesthesiology* 2001; **95**: 575–7
- 161 Roth S, Thisted RA, Erickson JR, Black S, Schreider BD. Eye injuries after nonocular surgery. A study of 60,965 anesthetics from 1988 to 1992. *Anesthesiology* 1996; **85**: 1020–7

- 162 Roth S, Tung A, Ksiazek S. Visual loss in a prone-positioned spine surgery patient with the head on a foam headrest and goggles covering the eyes: an old complication with a new mechanism. *Anesth Analg* 2007; **104**: 1185–7
- 163 Safar P, Aguto-Escarraga L. Compliance in apneic anesthetised adults. *Anesthesiology* 1959; **20**: 283–9
- 164 Sakka SG. Delayed complication of central venous catheterisation after prone positioning. *Intensive Care Medicine* 2001; **27**: 783–4
- 165 Satomoto M, Takagi Y, Igarashi H, Sato S. Hepatic infarction following prolonged prone position. *Masui* 2006; **55**: 1170–2
- 166 Schebesta AG, Wong TA. A method of spontaneously breathing anaesthesia in the prone position without endotracheal intubation [see comment]. *Anaesth Intensive Care* 1991; **19**: 88–91
- 167 Schmidt CR, Lincoln JR. Peripheral nerve injuries with anesthesia: a review and report of three cases. *Anesth Analg* 1966; **45**: 748–53
- 168 Schwann NM, Maguire DP, Roth JV, McNulty SE, Saouaf A. Evaluation of transesophageal atrial pacing in the prone and lateral positions. *J Cardiothorac Vasc Anesth* 2001; **15**: 192–6
- 169 Schwartz DM, Drummond DS, Hahn M, Ecker ML, Dormans JP. Prevention of positional brachial plexopathy during surgical correction of scoliosis. *J Spinal Disord* 2000; **13**: 178–82
- 170 Shenkin HN, Goldfeder P. Air embolism from exposure of posterior cranial fossa in prone position. *JAMA* 1969; **210**: 726
- 171 Shermak M, Shoo B, Deune EG. Prone positioning precautions in plastic surgery. *Plast Reconstr Surg* 2006; **117**: 1584–8; discussion 9
- 172 Sinha A, Agarwal A, Gaur A, Pandey CK. Oropharyngeal swelling and macroglossia after cervical spine surgery in the prone position. *J Neurosurg Anesthesiol* 2001; **13**: 237–9
- 173 Skeehean TM, Hensley FA, Jr. Axillary artery compression and the prone position. *Anesth Analg* 1986; **65**: 318–9
- 174 Slabaugh PB, Nickel VL. Complications with use of the Stryker frame. *J Bone Joint Surg Am* 1978; **60**: 1111–2
- 175 Smith R. The prone position. In: JT Martin, ed. *Positioning in Anesthesia and Surgery*. Philadelphia: WB Saunders, 1978
- 176 Smith RH. One solution to the problem of the prone position for surgical procedures. *Anesth Analg* 1974; **53**: 221–4
- 177 Smith RH, GZ, Volpitta PP. Problems related to the prone position for surgical operations. *Anesthesiology* 1961; **22**: 189–93
- 178 Soliman DE, Maslow AD, Bokesch PM, et al. Transoesophageal echocardiography during scoliosis repair: comparison with CVP monitoring [see comment]. *Can J Anaesth* 1998; **45**: 925–32
- 179 Soriano SG, McManus ML, Sullivan LJ, Scott RM, Rockoff MA. Doppler sensor placement during neurosurgical procedures for children in the prone position. *J Neurosurg Anesthesiol* 1994; **6**: 153–5
- 180 Srivastava S, Pandey CK. Anesthesia in the prone lithotomy position. *Can J Anaesth* 2001; **48**: 827
- 181 Stevens WR, Glazer PA, Kelley SD, Lietman TM, Bradford DS. Ophthalmic complications after spinal surgery. *Spine* 1997; **22**: 1319–24
- 182 Sudheer PS, Logan SV, Ateleanu B, Hall JE. Haemodynamic effects of the prone position: a comparison of propofol total intravenous and inhalation anaesthesia. *Anaesthesia* 2006; **61**: 138–41
- 183 Sunder G, Walloe A, Wingstrand H. A new device to reduce intra-abdominal pressure during lumbar surgery. *Spine* 1986; **11**: 635–6
- 184 Sunder-Plassmann G, Locker GJ, Muhm M, Thalhammer F, Laczika K, Frass von Friedenfeldt M. Central venous catheterization in a patient in the prone position. *Crit Care Med* 1997; **25**: 1439–40
- 185 Sutherland RW, Winter RJ. Two cases of fatal air embolism in children undergoing scoliosis surgery. *Acta Anaesthesiol Scand* 1997; **41**: 1073–6
- 186 Sutterlin C, Rehtine GR. Using the Heffington frame in elective lumbar spinal surgery. *Orthop Rev* 1988; **17**: 597–600
- 187 Szabo M, Denman W, Marota J, Roberts J. Evaluation of airway edema in patients operated on in the prone position. *J Neurosurg Anaesthesiol* 1997; **9**: 380
- 188 Takeuchi M, Morita K, Nakatsuka H, et al. A case of central retinal artery occlusion after anterior posterior fusion of the lumbar spine. *Masui* 2001; **50**: 899–901
- 189 Takizawa D, Hiraoka H, Nakamura K, Yamamoto K, Horiuchi R. Influence of the prone position on propofol pharmacokinetics. *Anaesthesia* 2004; **59**: 1250–1
- 190 Tarlov IM. The knee–chest position for lower spinal operations. *J Bone Joint Surg Am* 1967; **49**: 1193–4
- 191 Taylor AR, Gleadhill CA, Bilsland WL, Murray PF. Posture and anaesthesia for spinal operations with special reference to intervertebral disc surgery. *Br J Anaesth* 1956; **28**: 213–9
- 192 Teoh DCA, Williams DL. Adult Klippel–Feil syndrome: haemodynamic instability in the prone position and postoperative respiratory failure. *Anaesth Intensive Care* 2007; **35**: 124–7
- 193 Tettgenborn B, Caplan LR, Sloan MA, et al. Postoperative brainstem and cerebellar infarcts. *Neurology* 1993; **43**: 471–7
- 194 Tiefenthaler W, Gabl M, Teuchner B, Benzer A. Intraocular pressure during lumbar disc surgery in the knee–elbow position. *Anaesthesia* 2005; **60**: 878–81
- 195 Ting CK, Tsou MY, Su NY, et al. Repeated attacks of venous air embolism during craniotomy—a case report. *Acta Anaesthesiol Sin* 2001; **39**: 41–5
- 196 Tobias JD, Mencia GA, Atwood R, Gurwitz GS. Intraoperative cardiopulmonary resuscitation in the prone position. *J Pediatr Surg* 1994; **29**: 1537–8
- 197 Tobin A, KVV. Prone ventilation—it's Time. *Anaesth Intensive Care* 1999; **27**: 194–201
- 198 Toung TJ, McPherson RW, Ahn H, Donham RT, Alano J, Long D. Pneumocephalus: effects of patient position on the incidence and location of cerebrospinal fluid after posterior fossa and upper cervical cord surgery. *Anesth Analg* 1986; **65**: 65–70
- 199 Toyota S, Amaki Y. Hemodynamic evaluation of the prone position by transesophageal echocardiography. *J Clin Anesth* 1998; **10**: 32–5
- 200 Tsung Y-C, Wu C-T, Hsu C-H, Yeh C-C, Lin S-L, Wong C-S. Macroglossia after posterior fossa surgery in the prone position—a case report. *Acta Anaesthesiol Taiwan* 2006; **44**: 43–6
- 201 Turker RJ, Slack C, Regan Q. Thoracic paraplegia after lumbar spinal surgery. *J Spinal Disord* 1995; **8**: 195–200
- 202 Usher S. Use of the laryngeal mask airway in the prone position. *Hosp Med* 2004; **65**: 252
- 203 Valero R, Serrano S, Adalia R, et al. Anesthetic management of a patient in prone position with a drill bit penetrating the spinal canal at C1–C2, using a laryngeal mask. *Anesth Analg* 2004; **98**: 1447–50
- 204 Valls PL, Naul LG, Kanter SL. Paraplegia after a routine lumbar laminectomy: report of a rare complication and successful management. *Neurosurgery* 1990; **27**: 638–40
- 205 Van Aken H, Scherer R, Lawin P. A rare intra-operative complication in a child with Von Recklinghausen's neurofibromatosis. *Anaesthesia* 1982; **37**: 827–9
- 206 Vossler DG, Stonecipher T, Millen MD. Femoral artery ischemia during spinal scoliosis surgery detected by posterior tibial nerve somatosensory-evoked potential monitoring. *Spine* 2000; **25**: 1457–9

- 207 Wadsworth R, Anderton JM, Vohra A. The effect of four different surgical prone positions on cardiovascular parameters in healthy volunteers. *Anaesthesia* 1996; **51**: 819–22
- 208 Wakeno M, Sakamoto S, Asai T, Hirose T, Shingu K. A case of diaphragmatic paralysis in a patient with diabetes mellitus after surgery in prolonged prone position. *Masui* 2001; **50**: 1019–21
- 209 Walsh S, Bedi A, Miranda C. Successful defibrillation in the prone position. *Br J Anaesth* 2002; **89**: 799–800
- 210 Wang L-C, Liou J-T, Liu F-C, Hsu J-C, Lui P-W. Fatal ischemia stroke in a patient with an asymptomatic carotid artery occlusion after lumbar spine surgery—a case report. *Acta Anaesthesiol Taiwan* 2004; **42**: 179–82
- 211 Warner MA, Warner ME, Martin JT. Ulnar neuropathy. Incidence, outcome, and risk factors in sedated or anesthetized patients [see comment]. *Anesthesiology* 1994; **81**: 1332–40
- 212 Warner ME, Warner MA, Garrity JA, MacKenzie RA, Warner DO. The frequency of perioperative vision loss. *Anesth Analg* 2001; **93**: 1417–21
- 213 Wayne SJ. A modification of the tuck position for lumbar spine surgery. A 15-year follow-up study. *Clin Orthop* 1984; **184**: 212–16
- 214 Wayne SJ. The tuck position for lumbar-disc surgery. *J Bone Joint Surg Am* 1967; **49**: 1195–8
- 215 Weinlander CM, Coombs DW, Plume SK. Myocardial ischemia due to obstruction of an aortocoronary bypass graft by intraoperative positioning. *Anesth Analg* 1985; **64**: 933–6
- 216 Weis K. Threatening necrosis of the tip of the tongue during long-term anaesthesia in the prone position. *Der Anaesthetist* 1964; **13**: 241
- 217 Weksler N, Klein M, Rozentsveig V, et al. Laryngeal mask in prone position: pure exhibitionism or a valid technique. *Minerva Anestesiologica* 2007; **73**: 33–7
- 218 West J, Askin G, Clarke M, Vernon SA. Loss of vision in one eye following scoliosis surgery. *Br J Ophthalmol* 1990; **74**: 243–4
- 219 Wills J, Schwend RM, Paterson A, Albin MS. Intraoperative visible bubbling of air may be the first sign of venous air embolism during posterior surgery for scoliosis. *Spine* 2005; **30**: E629–35
- 220 Winfree CJ, Kline DG. Intraoperative positioning nerve injuries. *Surg Neurol* 2005; **63**: 5–18; discussion
- 221 Winter R, Munro M. Lingual and buccal nerve neuropathy in a patient in the prone position: a case report. *Anesthesiology* 1989; **71**: 452–4
- 222 Wolfe SW, Lospinuso MF, Burke SW. Unilateral blindness as a complication of patient positioning for spinal surgery. A case report. *Spine* 1992; **17**: 600–5
- 223 Wroski M, Ferber J, Wroski J. Acute tension pneumocephalus as a complication of surgical procedures of the posterior cranial fossa in prone position. *Neurol Neurochir Pol* 1987; **21**: 167–70
- 224 Yang S-H, Wu C-C, Chen P-Q. Postoperative meralgia paresthetica after posterior spine surgery: incidence, risk factors, and clinical outcomes. *Spine* 2005; **30**: E547–50
- 225 Yang YL, Lee YC, Lai HY, Lee Y. Nontraumatic subperiosteal orbital haemorrhage in an anaesthetised patient with surgery in the prone position. *Anaesth Intensive Care* 2007; **35**: 142–3
- 226 Yokoyama M, Ueda W, Hirakawa M, Yamamoto H. Hemodynamic effect of the prone position during anesthesia. *Acta Anaesthesiol Scand* 1991; **35**: 741–4
- 227 Yuen VMY, Chow BFM, Irwin MG. Severe hypotension and hepatic dysfunction in a patient undergoing scoliosis surgery in the prone position. *Anaesth Intensive Care* 2005; **33**: 393–9
- 228 Ziser A, Friedhoff RJ, Rose SH. Prone position: visceral hypoperfusion and rhabdomyolysis. *Anesth Analg* 1996; **82**: 412–5