9 Intracranial Procedures in the Prone Position

Mirza Pojskic and Kenan I. Arnautovic

Introduction

The ideal positioning of a patient involves balancing surgical comfort and optimal lesion exposure against the risks related to the patient's position [1]. The prone position is commonly used for approaches to the posterior fossa and suboccipital regions, for posterior approaches to the spine, and for approaches to posterior parietal and occipital regions as well as the pineal region. Because of the relatively higher complication rate of the sitting and semi-sitting positions, specifically due to venous air embolism, the prone position and its modifications (Concorde, arm-down Concorde, and semi-prone) are becoming more important in everyday surgical practice. Semi-prone, also known as the three-quarter prone or lateral oblique position, is discussed in Chap. 7 (Intracranial Procedures in the Lateral Position).

M. Pojskic
Department of Neurosurgery, Philipps University Marburg, Marburg, Germany

Department of Neurosurgery, Semmes-Murphey Clinic, University of Tennessee, Memphis, TN, USA

K. I. Arnautovic (✉)
Department of Neurosurgery, Semmes-Murphey Clinic, University of Tennessee, Memphis, TN, USA

Physiology of the Prone Position

The prone position is logistically a somewhat demanding position because of the challenges associated with providing adequate oxygenation, ensuring adequate ventilation, maintaining hemodynamics, and securing intravenous lines and the tracheal tube. Access to the patient's airway is poor, and pressure sores, vascular compression, brachial plexus injuries, air embolism, blindness, and/or quadriplegia can potentially occur [1]. Turning the patient prone from the supine position may increase intra-abdominal pressure, decrease venous return to the heart, and increase systemic and pulmonary vascular resistance. With either the head-up tilt or with the patient kneeling with flexed lower legs, venous blood pools in the lower part of the body, decreasing venous return and causing hypotension. For operations in the prone position, the patient is placed in a reverse Trendelenburg position of approximately 15° to promote venous drainage. Data suggest that the left ventricular ejection fraction and cardiac index may decrease, potentially causing hemodynamic instability. Oxygenation and oxygen delivery, however, may improve with prone positioning because of the improved matching of ventilation and perfusion, which occurs for three reasons. First, perfusion of the entire lungs improves. Secondly, the increase in intra-abdominal pressure decreases chest wall compliance, which, under positive-

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pressure ventilation, improves ventilation of the dependent zones of the lung. Thirdly, previously atelectatic dorsal zones of the lungs may open [1, 2]. When moving a patient into the prone position, an almost universal finding is a decrease in cardiac index (CI), up to an average of 24% [2, 3]. This was mainly as a result of decreasing stroke volume with little change in heart rate. Of the three factors involved in cardiac output (preload, afterload, and contractility), it seems likely that decreased preload was most to blame—compression of the inferior vena cava (IVC) reducing venous return to the heart. When the IVC is obstructed, blood uses a collateral return route—the vertebral wall venous plexuses [3].

The characteristic challenges with prone position include disconnection of pulse oximetry, the arterial line, and the tracheal tube, leading to hypoventilation, desaturation, hemodynamic instability, and altered anesthetic depth. To prevent complications from anesthesia, pulse oximetry and the arterial line could be left connected during the turn from supine to prone. Monitoring invasive blood pressure is especially important in patients with heart or lung disease and in trauma patients. For uncomplicated elective surgeries, when invasive blood pressure monitoring is not used, standard ASA monitoring could be applied [1, 4].

Influence of the Prone Position on Intracranial Pressure

It has been repeatedly observed that intracranial pressure (ICP) is lower in patients with supratentorial lesions operated on in the supine position than in those with infratentorial lesions operated on in the prone position [5].

Space-occupying lesions in the small infratentorial compartment induce higher ICP when compared with space-occupying lesions in the greater supratentorial compartment because the volume-pressure curve switches to the left. Rasmussen and Cold conducted two studies of ICP measurement during surgery with patients in the prone position, one regarding patients who underwent surgery for infratentorial lesions and one of those undergoing surgery for occipital lobe lesions. In both studies, ICP and jugular bulb pressure were significantly higher in patients in the prone position compared to those in the lateral and supine positions. The high levels of ICP during intracranial surgery with patients in the prone position (average of 18.3 mmHg for occipital lesions and 21.0 for infratentorial lesions) are associated with high jugular venous pressure (14.3 mmHg for occipital lesions and 12.1 mmHg for infratentorial lesions). The prone position also increases ICP and decreases cerebral perfusion pressure in patients with subarachnoid hemorrhage and acute respiratory distress syndrome [6]. Subdural ICP measurement can be used as a guide to prevent cerebral swelling after the dura is opened. Thresholds at which moderate cerebral swelling occurs are identical in supratentorial and infratentorial surgery. At an ICP below 5–7 mmHg, swelling rarely occurs. Above 13 mmHg, some degree of swelling is likely, and at 26 mmHg, pronounced swelling occurs. Therefore, when the ICP value reaches 13 mmHg, therapeutic measures to reduce it should be initiated [7].

The elevation of abdominal pressure leads to elevation of ICP. Transfer of pressure through the central venous system or by the cerebrospinal fluid (CSF) has been proposed as an explanation [8]. For this reason, laparoscopy should be used cautiously in patients with a baseline elevated ICP or head trauma, as intracranial pressure significantly increases with abdominal insufflation [9]. Prone position modifications that may reduce the ICP are placing the patient on the open frame Jackson table or on Wilson frame to allow for abdominal excursion along with how much this decreases the ICP.

Mechanical ventilation in the prone position and the use of positive end-expiratory pressure (PEEP) are frequently used techniques that improve oxygenation in patients at risk of respiratory failure [10]. Prone positioning can increase intracranial pressure (ICP) in patients with intracranial pathology by impairing jugular venous outflow [11]. PEEP can increase ICP and decrease mean arterial pressure, both resulting in decreased cerebral perfusion pressure (CPP) [12] by increasing central venous pressure and by impeding cerebral venous return to the right atrium. Consequently, in acutely brain-injured patients, ventilation goals are often in conflict with ICP control strategies [13, 14].

Recent study shows that in patients without head injury, ICP may increase in prone position, whereas the effect due to PEEP of 8 cm H_2O is negligible. TCD-derived formulae and optic nerve sheath diameter (ONSD) ultrasound measurement can be safe and easy techniques to non-invasively detect ICP, but ONSD seems to have the best performance in the detection of changes of body position [13].

The Full Prone Position: Technique and General Considerations

For purpose of this chapter, we will show the standard positioning for patient undergoing Chiari Type I Malformation surgery. These steps are standardized when performing the surgery of the posterior fossa, the pineal region and the occipital area. The different angles at which the surgical field has been observed is then achieved by manipulating the operative table. The first step in achieving an optimal prone position is to prepare the operating table (Fig. 9.1).

For the prone position, the patient is first anesthetized in the supine position on a bed or stretcher; the head is secured in a three-pronged head holder before the patient is turned prone [15] (Fig. 9.2).

A three-pronged head holder (e.g., the Mayfield head clamp) is often used to stabilize and maintain the head position of a patient during intracranial or posterior cervical spine surgeries. In adults, 60–80 pounds of force is applied across the three-point clamp to provide adequate fixation. In pediatric patients older than 3 years, a force of 30–40 pounds is applied, although for children ages 3–10 years, a horseshoe headrest can be used as an alternative. Complications associated with the use of the head clamp may include local puncture-site infection, scalp-vessel bleeding, air embolism, shunt-tube damage, epidural hematoma, chin and forehead pressure, skin necrosis, slippage of joints to the operating table, clamp breakage due to pressure of the transversal, and, rarely, depressed skull fracture. Twenty-six complications directly related to the use of head holders were identified through 19 papers published from 1981 to 2014: mainly skull fractures with or without a dural laceration (50%), epidural hematomas (23.8%), skull fractures with or without a dural laceration (50%), and air embolism (9.5%) [16]. To prevent these

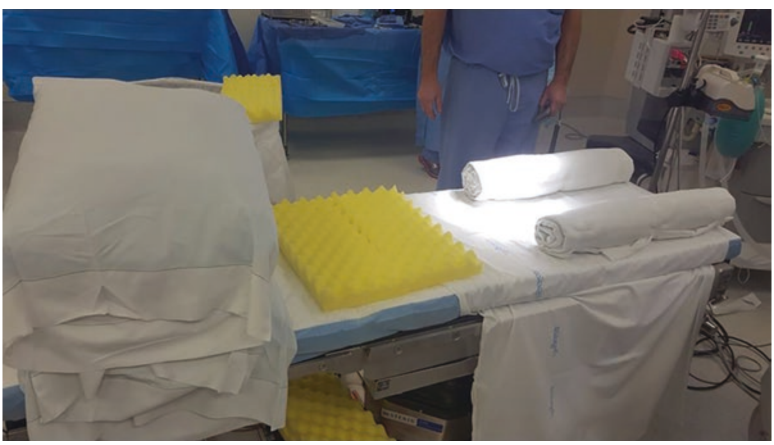

Fig. 9.1 Table setting for surgery in prone position. We use a standard sliding operating table. Note the previously prepared chest rolls, kneepads, padded footboard for the feet as well as pillows for elevation of the feet. Under the mattress is a towel which after the positioning is being performed is rolled around the positioned patient and secured with clamps

Fig. 9.2 First step in positioning the patient is to secure the head in a three-pronged head holder

Fig. 9.3 Position of pins of three-pronged head holder (Mayfield)

complications, the surgeon must take special care when fixing the head; for the prone position, the pins should be positioned two fingerbreadths above the external meatus. The pins must be placed correctly to avoid the areas of the frontal sinus, temporal fossa, major blood vessels, nerves, previous bone flaps, bone defect, abnormally thin or disease involved bone. The skull clamp must be applied along the centerline of the patient's head with the pins entering the skull perpendicularly; the chin and forehead should not be in direct contact with the rocker arm because of the risk of pressure necrosis [16]. Pin positioning is also important to prevent pin sliding, skin laceration, and loosening of the head (Fig. 9.3).

It is often necessary to disconnect intravenous or arterial catheters and the tracheal tube (if in position) during body positioning and during rotation/movement of the operating table. These changes sometimes create a complete "blackout" state, when the patient may not be monitored or oxygenated. Therefore, pulse oximetry and blood pressure should be monitored throughout positioning whenever possible, and chest tubes should not be clamped. The head should be kept neutral. All catheters, invasive monitors, and the tracheal tube should be carefully secured before the patient is turned prone.

In order to move a patient from the supine position on a stretcher to the prone position on the procedure table, there are few standard steps

Fig. 9.4 Head positioning for the Chiari decompression. Note the slight anteroflexion. Special consideration is being taken in preserving the physiological cervical alignment as well as preventing the pressure sores of the chin and forehead

which need to be done [17]. First of all, make sure an adequate number of personnel are available to accomplish this maneuver safely (minimum of four). Anti-embolic or sequential compression stockings must be applied before. Ensure that the table and the stretcher are of equal heights and safely locked in position. Note the position of all lines and tubes and place the patient's arms at the sides. To avoid pinching the arm between the stretcher and the table or a possible shoulder dislocation, be sure that the arm that will be the down-side arm is secure [17].

To move the patient into the prone position, we use a log roll maneuver. The anesthesia provider coordinates the move and is responsible for the patient's head. Turners turn the patient from the stretcher side and receivers receive the patient on outstretched arms from the opposite side of the table. An additional assistant stands at the patient's feet. Remember to lift, not pull. Lifting will avoid shearing, which can result in tissue injury [17].

Once the patient has been successfully turned, the head will face down in a head support device. The core rule of positioning of the head is the preservation of the physiological cervical alignment. Therefore, hyperflexion or hyperextension should be avoided. For Chiari decompression, we would slightly perform a slight anteroflexion in order to expose the craniovertebral junction (Fig. 9.4), lesions of posterior fossa and pineal region require even more anteroflexion. Lesions of the occipital lobes could be positioned either in moderate flexion or extension. Changing the position of the table during the procedure (Trendelenburg and reverse-Trendelenburg) provides better view of the surgical field at the given moment of surgery.

It is essential to perform the preoperative neck evaluation in every patient. Between 17 and 86% of patients with rheumatoid arthritis will have evidence of cervical spine disease 5 years after diagnosis. The main concern is an iatrogenic spinal cord injury during the positioning of the head and neck during the intubation phase of the procedure, as well as when assessing the amount of flexion and extension in prone position. To overcome this, any patient with a spine classed as unstable the anesthetist may perform an awake fiber-optic intubation in place of the traditional intubation [18]. While there are no clinical guidelines regarding preoperative imaging of the cervical spine in patients with RA, clinicians must be aware of the risk of cervical instability, which may be asymptomatic. If performed, radiology imaging should include at least flexion-extension views of the cervical spine [19]. When placing patient prone special care needs to be taken when osteoporosis, instability in the cervical spine as well as metastatic spine disease are present.

Protecting the eyes is paramount, and appropriate lubrication and closure of the eyelids are necessary. The eyes are at particular risk for compression injuries. Direct pressure on the eyes should be avoided by not using a horseshoe-shaped headrest. The eyes should be gently taped shut. The patient's chin must be free of the table and frame.

Pressure sores (e.g., on eyes, breasts, the penis, soft tissue at the joints, ears) are the most frequent complications of prone positioning [15]. Prone position caries a high risk of eye compression, venous embolism, increased airway pressure, edema of face, tongue and neck, endotracheal tube migration as well as hypotension and dysrhythmias.

Special frames (e.g., Wilson, Relton-Hall, Andrews), which support the chest but leave the abdominal wall and pelvis free, may be used, as well as chest rolls. We prefer to use chest rolls in form of rolled sheets, as they are less traumatic to the breast, especially in female patient, furthermore chest rolls in contrast to frames do not press the diaphragm on its entire length and so enable the free motion of the abdomen (Fig. 9.5). Free movement of the abdominal wall is desirable for three reasons: improved excursion of the diaphragm and improved oxygenation ventilation, a decrease in intra-abdominal pressure and surgical bleeding, and improvement of venous return from the legs and pelvis [1]. Monitoring intra-abdominal pressure with an intravesicular transducer can be considered for high-risk patients or high-risk procedures.

The breasts, especially in women, must be medially displaced, with no pressure on the nipples. Large breasts are subject to greater direct pressure and these can be in exceptional cases moved laterally so that the patient's weight does not injure them. In addition, patients with breast implants have a theoretical risk of rupture and risk of breast necrosis with the direct pressure applied in prone position [20, 21]. The groin and knees should be appropriately padded, and the abdomen kept as free as possible. The femoral artery or peripheral leg pulses should be checked and recorded as they are an indicator that the abdominal aorta and femoral vessels are not unduly compressed. The presence of these pulses is evidence that the renal arteries are patent, with adequate perfusion to the kidneys. The male genitalia should be confirmed to be in a downward natural position to avoid compression or torsion injury. The electrocautery grounding plate must not be permitted to touch them.

The arms are positioned at the patient's side, with the palms facing the patient and the thumbs down. To prevent nerve compression, appropriate supportive padding should be used under bony surfaces where superficial nerves are known to travel. The axillas, elbows, and hands are padded. The shoulders may be taped so that they do not drift, and the arterial arm pulse should be checked after taping to detect any obstruction of blood flow [15]. If abduction is used, great care must be exercised to prevent hyperextension of the arms, thereby avoiding injury to the brachial plexus. Arm abduction, however, impedes the position of the surgeon [1] (Fig. 9.6).

Full neck flexion can be reduced with proper head and neck support. Body alignment is very important and should be confirmed by the surgical team. The cervical spine should be in alignment with the rest of the spine, with no torsion or

Fig. 9.5 Note the chest rolls with medially placed breasts. Chest rolls stretch from acromioclavicular joints to iliac crest, allowing chest movement and decreasing abdominal pressure. Be careful that the chest roll does not extend beyond the iliac crest, as this would compress the femoral nerve and artery [17]

Fig. 9.6 Palms are turned inwards and padded with foam pads

Fig. 9.7 Positioning of the legs. Sequential compression devices are applied to prevent blood clot formation in lower extremities

twisting, and the legs parallel to each other. A foot support or other method of stabilization, such as a belt apparatus placed strategically, may also be necessary to keep the patient from sliding down the table. The patient's feet should be kept off the bed surface to prevent pressure sores. Padding should be placed under each patella of the knee joints. A pillow should be placed under the ankle joints to elevate the foot to relieve tension on the sciatic nerve and prevent the toes from resting on the OR table mattress (Fig. 9.7).

The patient's face must be carefully checked when positioning is completed and the headrest and head should stay in the same relative positions. A chin bar can be used to reduce soft-tissue compression, and a bite block prevents tongue compression. In addition, oral airways can put increased pressure on the tongue, which should be taken into consideration. There should be no movement of the patient down the table, nor should the surgeon reposition the head during surgery without specifically checking for pressure on the patient's face. Obese patients may be at particular risk because of restricted diaphragmatic movement and high intrathoracic pressure [22] (Fig. 9.8).

The safety strap should not be placed until after the patient has been positioned. If the safety strap is placed prior to the positioning, such as during movement of the patient on the OR table, the safety strap could cause shearing and friction injuries.

After positioning of the arms and the legs as well as checking the potential pressure sites (acromion processes, breasts, iliac crest, male genitalia, patellae, and toes) the towel which lies underneath the chest rolls and the kneepads is being rolled around the patient and secured with clamps. Additional tape is stretched between shoulders and the foot pillows, retracting the shoulders posteriorly (Figs. 9.9 and 9.10).

Fig. 9.8 Face position. Chin is not being compressed. Eyes are shut with tape with protective padded glasses. For procedures with motor evoked potential monitoring we include the bite block for the teeth which is not included in this slide

The Concorde Position: Technique and General Considerations

The Concorde position is a modification of the prone position and is used for occipital, transtentorial, and supracerebellar infratentorial surgical approaches. In this modification, the patient's head is typically skeletally flexed and fixed, but may be laterally flexed if needed. The body is placed in the reverse-Trendelenburg position and chest rolls are placed under the trunk. The patient's arms are tucked alongside the trunk, and the knees are flexed [1].

Positions used for pineal surgery include the sitting, prone, and semi-prone. In 1983, Kobayashi and associates [9] described a modified prone position, the Concorde position, for supracerebellar infratentorial approaches to this area. In this modification, the patient is placed prone as far to the surgeon's side of the operating table as possible, and the patient's head is fixed in the head frame with the head flexed and elevated higher than the heart. After craniectomy, the head is tilted to the right, away from the surgeon, and returned to the original position before wound closure. While operating from behind the patient's shoulder, the surgeon (right-handed) usually works on the left side of the patient (left Concorde position), or occasionally on the right side when a lesion is located on the left side (right Concorde position) [23]. The midline suboccipital craniotomy or craniectomy is made with the head in a neutral position. The surgeon is positioned to the left, right, or rostral side of

Fig. 9.9 Note the shoulder taping technique

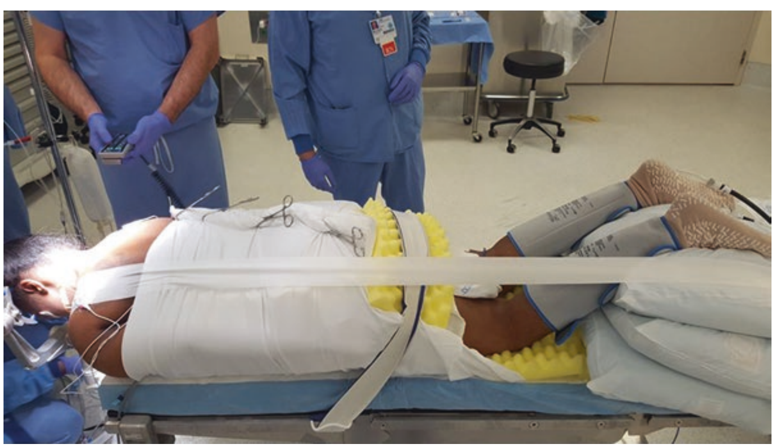

Fig. 9.10 Final preoperative position of the patient

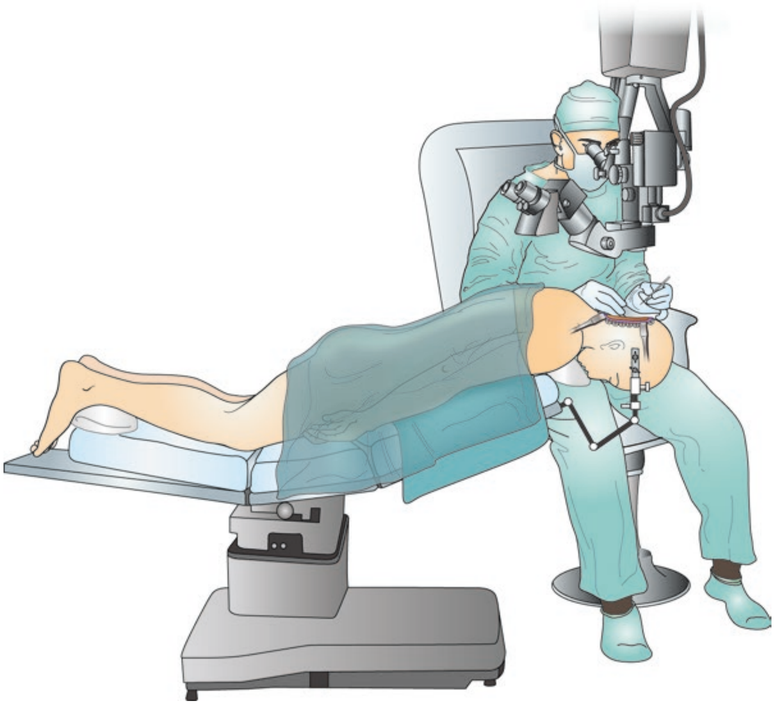

Fig. 9.11 Concorde position. The patient's head is positioned in flexion and is elevated above the level of the heart, while the surgeon sits on the left side of the patient and approaches from behind the patient's left shoulder

the patient, who is in the prone position for the craniotomy. The microscope is introduced at or after the opening of the dura mater, and the surgeon stands or sits to the left of the patient looking toward the cerebellum. The neutral head position is needed for the craniotomy to divide the occipital muscles symmetrically. Then, the patient's head is tilted to the right and the face is turned to the right before the microscope is introduced. The surgeon is able to keep the midline axis of the patient's head straight without discomfort and surgical manipulation is accurate and easy [24] (Fig. 9.11).

When the microscope is introduced after the craniotomy with the head neutral, there was formerly a need to release the holding arm of the head frame and adjust the position. It has also been necessary to reverse this adjustment during wound closure. To release the holding arm twice during the operation has proved troublesome, and Takasuna and Tanaka developed a modification to prevent this problem—the "skew head rotation"—in which the head can be tilted simultaneously only by rotating the head frame. In this maneuver, special care is required to prevent excessive rotation so as not to strain the patient's neck. The Sugita head holder, for example, offers a range of up to 36° of rotation to both the left and right. As the human cervical spine can rotate up to about 68°, this modified position is safer because the required head rotation is only about 30º. Nevertheless, there is individuality in the rotational range of the cervical spine, and the range of the patient's neck rotation should be verified before anesthesia is induced. In addition, it is important to confirm that the head is safely rotated just before draping [24].

In the Concorde position, however, the patient's shoulder closest to the surgeon occasionally interferes with the visual route and surgical manipulation. Although the involved shoulder is usually taped down from the neck and head, this arrangement is occasionally inadequate, especially in the case of a muscular patient. To prevent this difficulty, Kyoshima developed a modified Concorde position [25] (Fig. 9.12). The procedure for this position is almost the same as for the Concorde position. The patient is placed prone and, before the patient's head is fixed in the head frame, the patient's arm on the surgeon's side is placed to hang down over the head end of the operating table, with elbow flexion supported by an arm holder. The axilla is carefully padded to prevent compression. The patient's head should also be positioned with the chin—not the neck—down to enhance the visual route. This arm-down Concorde position allows good access to the pineal and supracerebellar regions and the pons in patients who are muscular, broad-shouldered, short-necked, or obese.

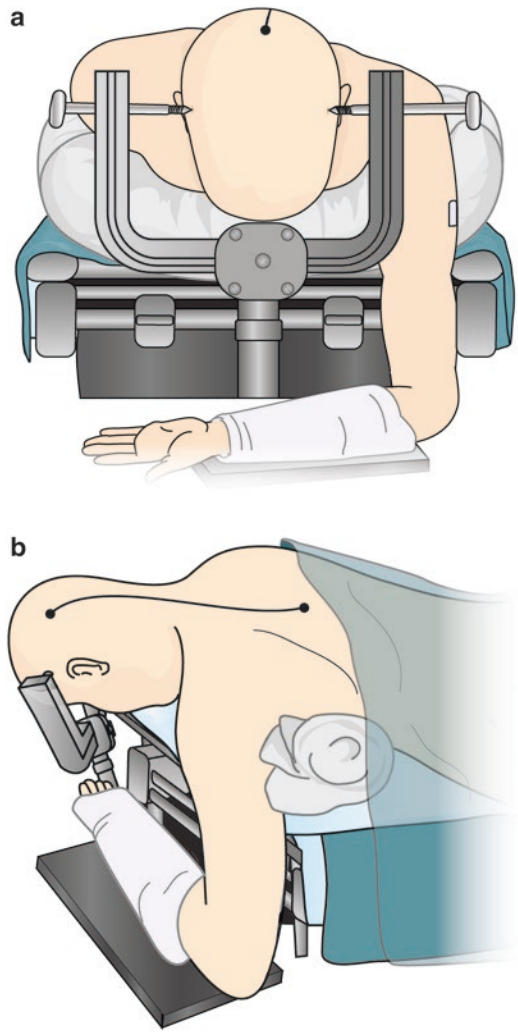

Fig. 9.12 Arm-down Concorde position. (**a**) The patient's left arm is placed hanging down over the head end of the operating table, with elbow flexion supported by an arm holder. (**b**) Note that the patient's left shoulder is lower than the right, and thus interferes less with the surgeon's view

Indications

The prone position can be used for both supra- and infratentorial surgery. Supratentorial lesions are those of the posterior parietal and occipital regions, and include intracerebral hematomas, metastases, gliomas, abscesses, meningiomas, cavernomas, arteriovenous malformations (AVMs), convexity meningiomas and meningiomas of the posterior third of the falx, falcotentorial meningiomas, and tumors of the pineal region. The full prone position is particularly useful in situations in which a bilateral craniotomy is needed (e.g., bilateral occipital falx meningiomas). Infratentorial lesions include inferior tentorial meningiomas, cerebellar primary tumors and metastases, brainstem tumors, posterior-inferior and anterior-inferior cerebellar artery aneurysms, Chiari malformations, fusion procedures in the craniocervical region, and intracerebellar hematomas [22, 26–28].

Supratentorial Lesions

The full prone position can be used for supratentorial approaches, particularly those utilizing the transcallosal route. This includes lesions of the posterior parietal and occipital regions, the posterior third of the falx, and the pineal region. The steep angle of the tentorium makes it difficult to use this approach for infratentorial lesions, and the Concorde position has been advocated for infratentorial lesions, particularly in the pediatric population (Fig. 9.13).

Infratentorial Lesions

There are four main positions to consider for surgery in the posterior fossa: the prone/Concorde position, the lateral decubitus/park-bench position, the supine position with rotation of the head, and the sitting position. The prone and Concorde positions are used when a midline approach is necessary, and the patient is lying prone with support for the thorax, pelvis, and legs. This support should leave the abdomen free. A U-cushion can be placed under the thorax, and the head is supported by a horseshoe cushion or fixed in the head clamp. The clamp allows more freedom to flex the head with concomitant better exposure of the lower occiput and neck. Such exposure can be exaggerated by lifting the upper thorax and shoulders and bending and lowering the head to the maximal flexion. In such a position, the surgeon may stand on one side

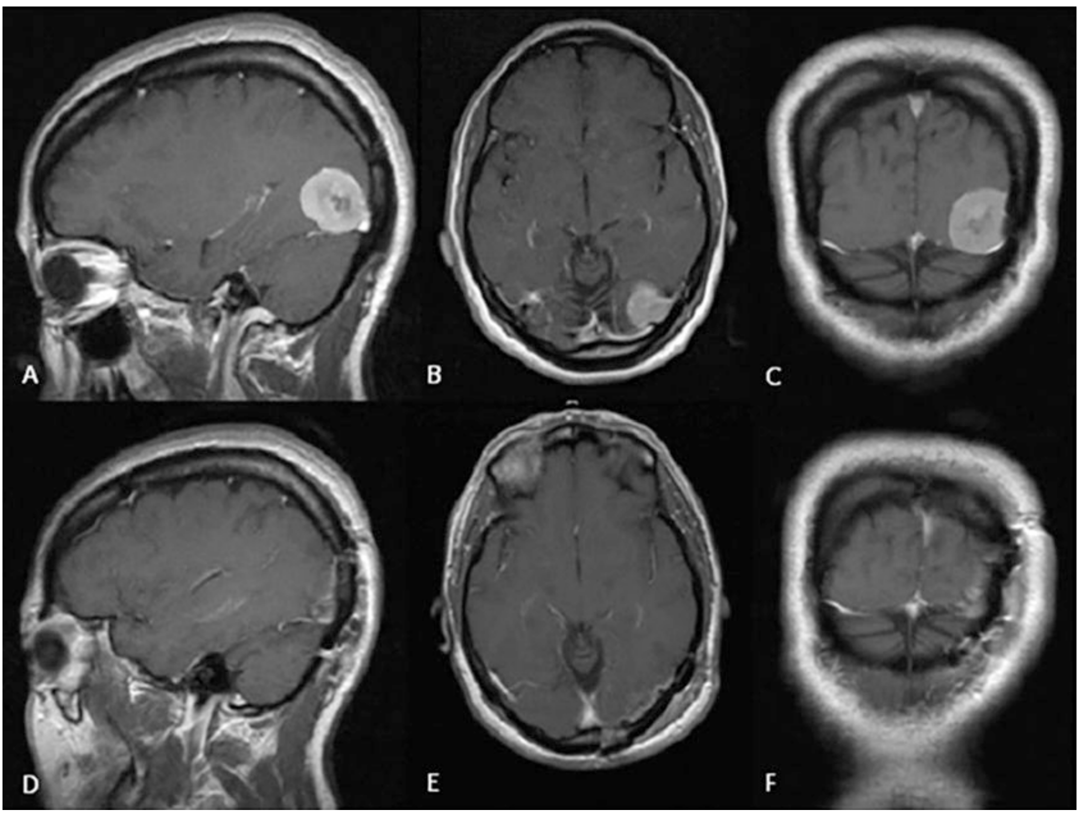

Fig. 9.13 A 38-year-old female patient with severe headaches and bilateral papilledema. Occipital meningioma with narrowing of the transversal sinus. (**a**) preoperative T1 post-contrast MRI of the brain, sagittal view. (**b**) axial view. (**c**) coronal view. (**d**) postoperative T1 post-contrast MRI of the brain, sagittal view. (**e**) axial view. (**f**) coronal view

of the body looking down toward the occipital region. Therefore, the head can even be angulated and tilted a little, according to the surgeon's preference. Especially in Concorde hyperflexion, the surgeon may work "upside down," standing and even sitting with the patient's head in his/her lap. The prone position can be also used for the far lateral approach. After full exposure, the table (with the patient well secured to it) may be turned and tilted as far as is necessary [29].

Lesions of the Cerebellum and Brainstem

A midline or a paramedian posterior approach is useful for cerebellar, fourth ventricular, and brainstem lesions. The most common lesions are metastatic brain tumors (Fig. 9.14), followed by cerebellar hemorrhages, cerebellar infarctions, and AVMs. A paramedian approach is also required for aneurysms of the distal posterior-inferior cerebellar artery.

A midline approach is used for suboccipital decompression of Chiari malformations (Fig. 9.15), as well as for dorsal foramen magnum meningiomas. Brainstem lesions that may be approached include cavernomas, small AVMs, exophytic brainstem gliomas, fourth ventricle cysts, choroid plexus granulomas, subependymal astrocytomas, and ependymomas (Fig. 9.16).

Vascular lesions, such as posterior-inferior cerebellar artery aneurysms and AVMs involving the cerebellar hemispheres and cerebellopontine angle, usually present with hemorrhage. Patients with increased intracranial pressure and hydrocephalus require initial placement of a ventriculostomy. The prone position is more suitable for

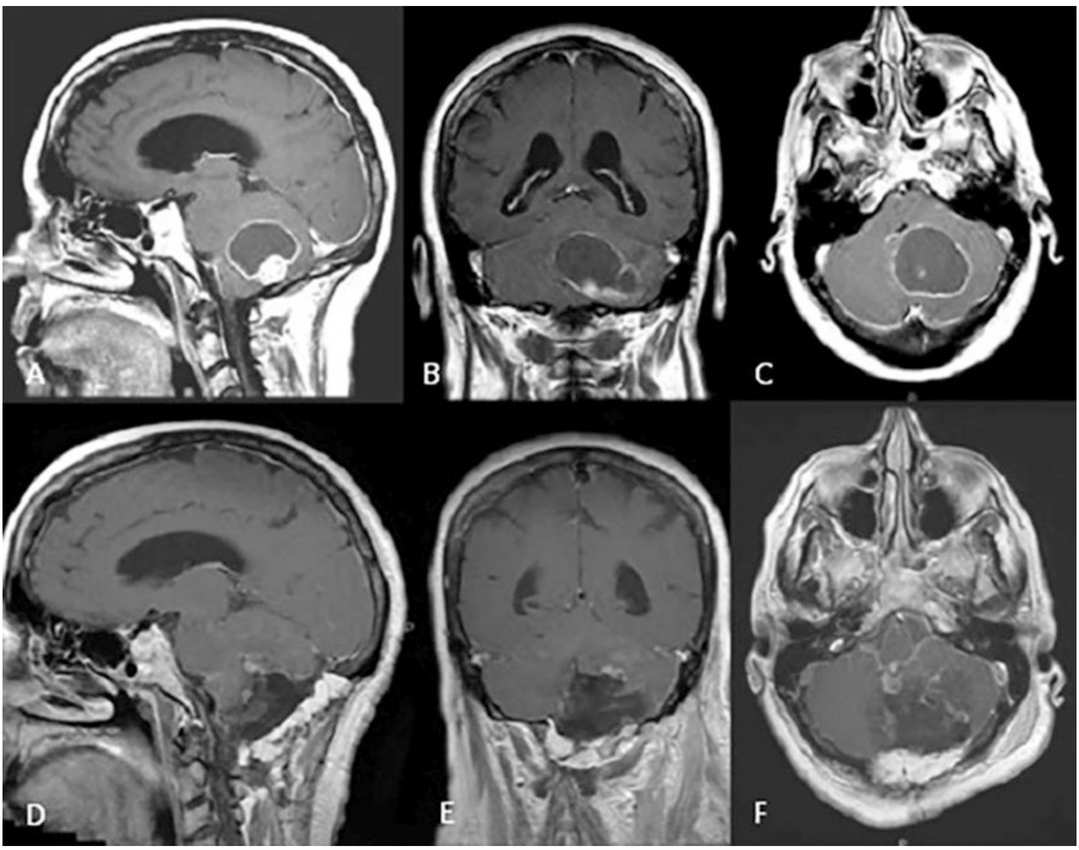

Fig. 9.14 A 62-year-old female patient with dizziness and balance problems. Metastatic lung adenocarcinoma. (**a**) preoperative T1-weighted post-contrast MRI of the brain, sagittal view. (**b**) coronal view. (**c**) axial view. (**d**) postoperative T1 post-contrast MRI of the brain, sagittal view. (**e**) axial view. (**f**) coronal view. Note the fat tissue graft placed along the dura for prevention of the CSF-related complications

midline lesions while the semi-prone position is better for paramedian lesions. These positions provide the same exposure as the semi-sitting position; in addition, the patient's table can be tilted up or down to decrease venous drainage in a controlled fashion. A vertical midline incision is made for midline lesions. For paramedian lesions, the incision starts in the midline and curves below the inion in an inverted U, toward the mastoid process [30].

Fig. 9.15 A 32-year-old female patient with headaches. (**a**) preoperative T2-weighted MRI of the cervical spine depicting Chiari Malformation Type I with syringomyelia, sagittal view. (**b**) postoperative T2-weigted MRI of the cervical spine after the decompression of the posterior fossa with resection of the atlas arch, sagittal view. Note the resolution of the syrinx

AVMs of the vermis and cerebellar tonsils are best handled through a midline suboccipital exposure. For this, the patient is positioned prone on chest rolls with the back elevated. It is helpful to angle the head toward the opposite shoulder, allowing the surgeon better access to the midline without having to lean over the patient's back. A midline incision is made from above the inion to the level of the spinous processes of the fourth cervical vertebra [31].

Lesions of the Pineal Region

Although the sitting position is commonly used with approaches to the pineal region, several disadvantages may make the prone or semi-prone position, which provides identical exposure, a better choice. First, patients with pineal region lesions usually have to be placed in a more erect position than in the semi-sitting position, making the danger of air embolism considerable. The sitting position also makes the operation particularly difficult and tiring for the surgeon because it requires a long reach for the instruments and that the arms be held in an extended, elevated position for many hours [30]. Although this arrangement is generally comfortable for the surgeon, the operative field is considerably elevated, which can make it difficult for the surgeon to be seated. This position enables

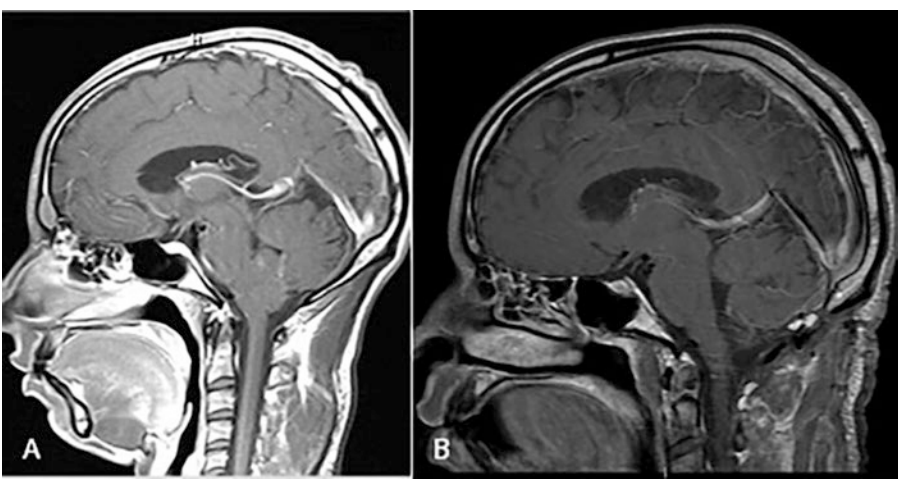

Fig. 9.16 A 39-year-old male patient with severe headaches and balance problems. (**a**) preoperative T1-weighted post-contrast MRI of the brain which shows the tumor on the floor of the fourth ventricle. (**b**) postoperative T1-weighted post-contrast MRI of the brain which shows the complete resection of the tumor (subependymoma)

the use of a bridge on the operating microscope, affording binocular vision for both the surgeon and the assistant. In the Concorde position, the patient's head may be rotated 15° away to facilitate occipital lobe retraction.

Posterior approaches to the pineal region may be divided into supra- and infratentorial. Supratentorial approaches include the occipital transtentorial, interhemispheric transcallosal, and interhemispheric retrocallosal. Infratentorial approaches include the median and paramedian supracerebellar infratentorial approaches. The occipital interhemispheric transtentorial approach and supracerebellar infratentorial approach are the ones most commonly used for the pineal region [32].

The posterior interhemispheric approach has traditionally been used for tumors located at the posterior third ventricle, pineal tumors growing superiorly or laterally to the trigone and lateral ventricle, tumors around the vein of Galen, and tumors of the median occipital lobe, as well as tumors of the splenium of the corpus callosum, brainstem tumors, vascular malformations, P2/3 segment aneurysms of the distal posterior-inferior cerebellar artery, cavernomas of the dorsal midbrain, and lesions of the superior vermian area. The advantage of this approach is that is allows early access to the superior cerebellar artery, a major artery feeding these tumors. It also affords better exposure of the veins in the quadrigeminal region and shortens the distance to the area because of the division of the tentorium [32]. Depending on the anatomy of the pineal region tumor (meningioma, pinealoblastoma, pineal cyst), additional resection of the splenium or tentorium is sometimes needed. Various positions have been described for this approach (semi-sitting, lateral, three-quarter prone, and semi-prone) [30].

The supracerebellar infratentorial approach is used for lesions in the pineal quadrigeminal area. For these, the patient may be placed prone with the surgeon seated near the patient's head, looking in the reverse direction. Alternatively, the patient may be placed in the semi-prone position with the surgeon looking at an angle from behind [30] (Fig. 9.17).

The combined occipital transtentorial supracerebellar trans-sinus approach is used for giant tumors of the pineal quadrigeminal area or meningiomas. It combines the advantages of the supracerebellar, infratentorial, and occipital transtentorial approaches [32] (Fig. 9.18).

Complications

Increased age, elevated body mass index, the presence of comorbidities, and long.

duration of surgery appear to be the most important risk factors for complications associated with prone positioning. The systematic use of checklists is recommended to guide operating room teams and to reduce prone position-related complications [33].

Complications associated with prone position include injury to the central and peripheral nervous system, ophthalmic injury, and pressure injuries [3]. Injury to the central nervous system occurs due to the rise of the intracranial pressure. There are few strategies which could be used in situation when intraoperative swelling occurs. These include releasing the cerebrospinal fluid from the cisterns, extending the decompression of the posterior fossa and placing a ventricular catheter at the Frazier point. Further maneuvers include tilting the table with head up, hyperventilation, hypertonic saline (especially in patients with renal failure), or mannitol. Injuries to central nervous system can occur when turning the patient from supine to prone or due to neck extension (occlusion of the carotid or vertebral arteries), as well as due to pneumorrhachis (air entrainment into the spinal canal) after posterior fossa exploration, which can result in quadriplegia [3, 34]. Quadriplegia can also occur due to excessive neck flexion in the "Concorde" position with the neck flexed and the chin approximately one fingerbreadth from the sternum in a patient with narrow spinal canal and herniated discs [35], which emphasizes the importance of the preoperative neck evaluation. Pressure injuries can be divided into direct and indirect [3]. Direct pressure injuries include pressure necrosis of the skin, contact dermatitis, tracheal

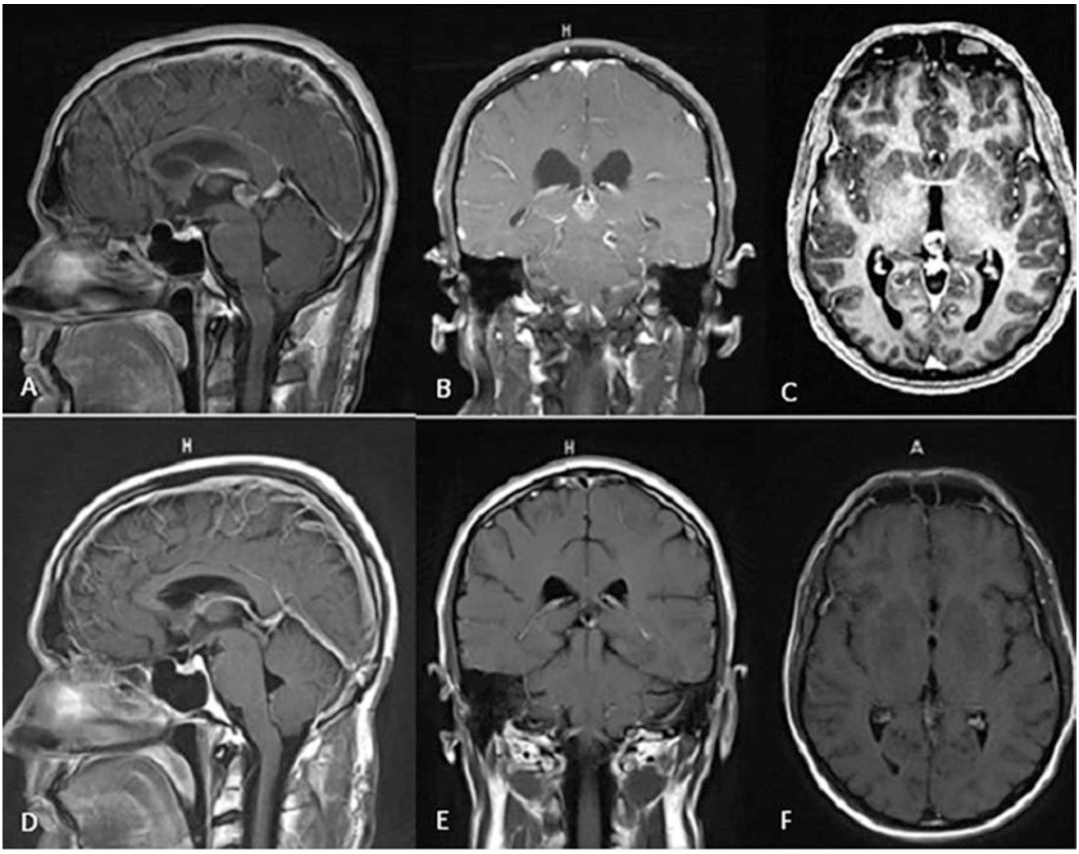

Fig. 9.17 A 31-year-old patient with diplopia and Parinaud syndrome. (**a**) preoperative T1-weighted post-contrast MRI of the brain, sagittal view, which shows lesion in the pineal region (germinoma), (**b**) coronal view; note the enlarged ventricles due to occlusive hydrocephalus; (**c**) axial view. (**d**) postoperative T1-weighted post-contrast MRI of the brain, sagittal view, which shows the complete resection of the tumor. The procedure was performed in the prone position with supracerebellar infratentorial approach performing the resection of the tentorium. (**e**) coronal view; note the fat patch used to prevent complications due to leak of the cerebrospinal fluid; (**f**) axial view, note that the ventricles returned to normal size

compression, salivary gland swelling, and shoulder dislocation. Indirect pressure injuries involve macroglossia and oropharyngeal swelling, mediastinal compression, visceral ischemia, avascular necrosis of the femoral head, peripheral vessel occlusion, and limb compartment syndromes and rhabdomyolysis.

Three types of complications have been associated with the prone position in cranial and spine surgery: those arising as a direct result of the positioning method, those due to venous air embolism, and those resulting from anesthesia [15].

Complications that arise as a direct result of the method of positioning include postoperative vision loss, myocardial ischemia, increased abdominal pressure and bleeding, abdominal compartment syndrome, limb compartment syndrome, shoulder dislocation, nerve palsies, pressure sores, hepatic dysfunction, and cardiovascular compromise. Rates of pressure sores as an intraoperative complication have been reported to range from 5 to 66%. As such, pressure sores lead to longer hospital stays and higher healthcare costs [20]. Retinal artery occlusion as a result of direct pressure on the eye lobe can lead to postoperative blindness. The rate at which this complication occurs increases relative to risk factors such as diabetes, obesity, smoking, and

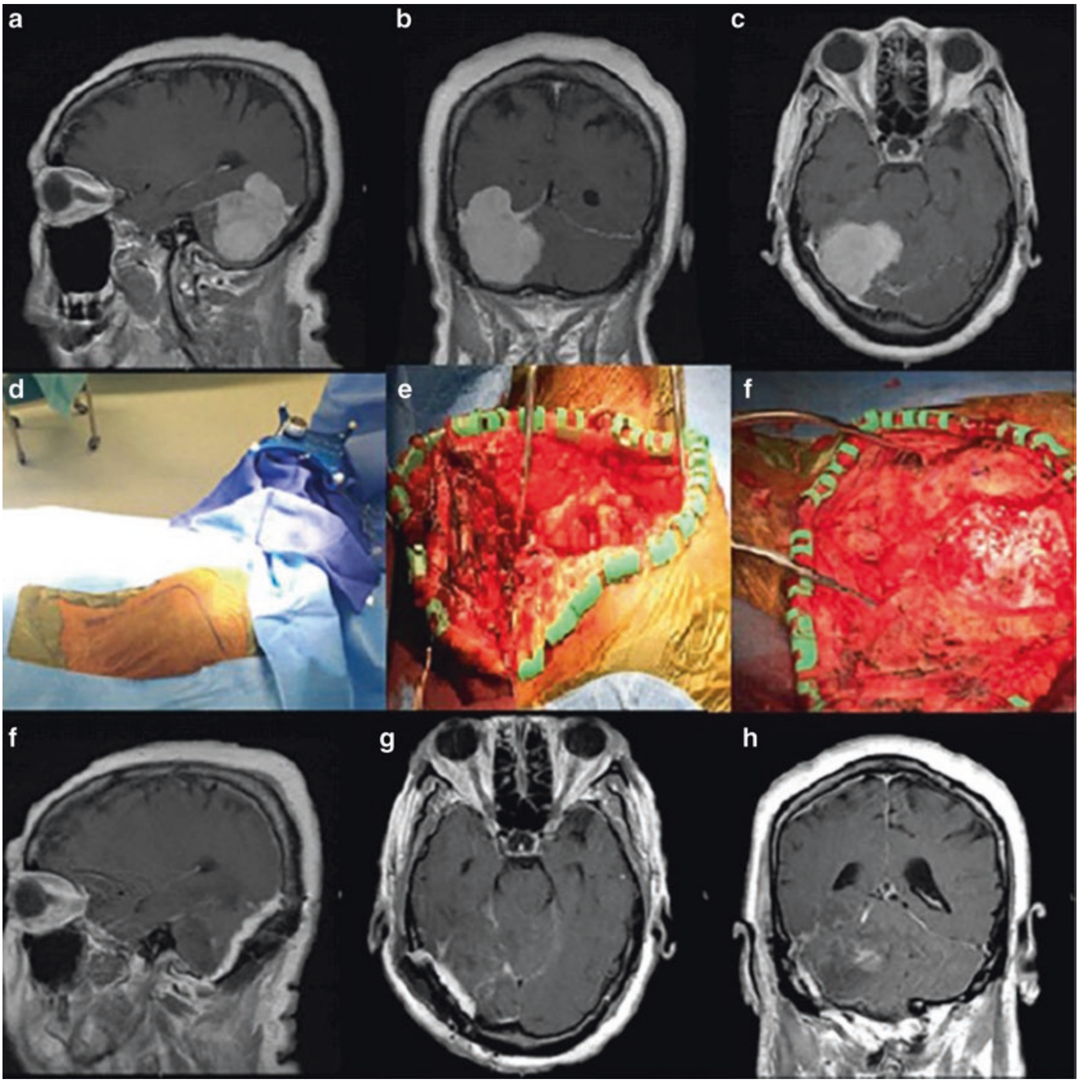

Fig. 9.18 A 74-year-old female patient with headaches, dizziness, and balance problems. (**a**) preoperative T1-weighted post-contrast MRI of the brain, sagittal view, which shows supra- and intratentorial meningioma. (**b**) coronal view; (**c**) axial view. (**d**) Note the midline incision which is curved to the right above the inion; (**e**) intraoperative photo, exposing the bone; (**f**) supra- and infratentorial craniotomy. (**g**) postoperative T1-weighted post-contrast MRI of the brain, sagittal view, which shows the complete resection of the tumor. (**h**) axial view; note the fat patch used to prevent CSF complications; (**i**) coronal view

hypertension, and risk factors related to the surgical procedure such as anemia, decreased venous return, and prolonged hypotension. Corneal abrasion is also very often complication of Trendelenburg position [34]. Anemia, hemodilution, blood loss (>1000 mL), and hypotension, in combination with the increased ocular pressure in the prone position, can reduce perfusion pressure to the optic nerve and cause ischemic optic neuropathy [20].

Skin excoriations can occur on shoulders associated with taping. Wrist drop can be associated with pressure on the radial nerve above the elbow associated with securing straps or equipment compression. Brachial plexus injuries or lesions can occur as a result of excessive stretching and incorrect shoulder positioning that may cause transitory or permanent sensory and/or motor deficit. Another complication reported is ulnar neuropathy, which may be caused by entrapment of the ulnar nerve at the elbow or wrist with resultant numbness and tingling in the fourth and fifth fingers. This complication may be caused by mal-positioning or the lack of adequate padding during surgical positioning. There have also been a few cases of reported in association with prone positioning during surgery, with visceral hypo-perfusion implicated in those cases4. When a surgical patient is in the prone position (Jackson table), increased pressure on muscles can lead to muscle hypo-perfusion and ischemia as well as subsequent reperfusion injury with release of myoglobin. This could lead to rhabdomyolysis and acute renal failure [36]. Pressure to penis and scrotum can lead to scrotal edema.

Luostarinen and associates showed that, compared with the prone position, surgery with the patient in the sitting position does not require excessive fluid administration to achieve stable hemodynamics [37]. Risk factors for reduced stroke volume, cardiac index, raised central venous pressure, and low blood pressure include massive blood loss, hypothermia, fluid shifts, cardiac comorbidities, venous air embolism, and anatomic deformities such as thoracic lordosis or pectus excavatum, which can aggravate hypotension. Also, an increase of intra-abdominal pressure in the prone position of more than 12 mmHg increases the risk for abdominal compartment syndrome, as visceral compression and intra-abdominal hypertension caused by decreased perfusion pressure lead to multi-organ failure. Patients with previous abdominal surgeries are at particularly high risk as tight abdominal closures can reduce abdominal compliance, increasing abdominal pressure. Lower limb compartment syndrome and rhabdomyolysis are common complications associated with placement in non-supine positions.

The risk of venous air embolism (VAE) is not confined to neurosurgical procedures done with the patient in the sitting position, nor is it eliminated by placing the patient horizontally. Avoiding techniques that enhance air entrainment or increase bubble size is imperative, as is identifying the population at risk of its devastating sequela, paradoxical air embolism. Children are at increased risk of VAE, as their reported rate of VAE (73%) is significantly higher compared with that of adults (37%) [38]. Surgery with the patient in the sitting position has the highest rate of VAE. It may also occur in patients in the prone position during intracranial procedures; the reported rate ranges from 10 to 25% [38]. The diagnosis of VAE can be made with capnography (a sudden drop in end-tidal CO_2), precordial Doppler (with the transducer placed in the area of right atrium), and transesophageal echocardiography (the most sensitive invasive method, essential in patients with a patent foramen ovale). Supplementary monitoring is directed toward prompt detection and early treatment of VAE. Transesophageal echocardiography and Doppler were found to be equally sensitive with respect to air detection, and transesophageal echocardiography provided the added benefit of localizing intracardiac air within a specific cardiac chamber. Cardiovascular changes occur late and include hypotension, elevation of central venous pressure, and electrocardiogram changes. TEE is not routinely used in prone position for monitoring due to the risk of compression of the base of the tongue with postoperative edema.

VAE may increase airway pressure during mechanical ventilation as a result of bronchoconstriction and reduced pulmonary compliance. Intermittent positive-pressure ventilation has been advocated to prevent the reflex gasp that occurs with an air embolus and may cause a bolus of air to be sucked into an open vein. Initial exposure of the posterior fossa, when air may enter the diploic and emissary veins or the dural sinuses, is the time of greatest concern for the development of VAE. Sources of VAE are often not identified, but careful surgical technique is paramount. Bone was identified as a source of VAE in 16% of cases in one study; hence, the recommendation that all bone edges be waxed. Pin-type head holders have also been implicated, and it has been suggested that these pins be wrapped with gauze impregnated with petrolatum or bismuth tribromophenate [38, 39] Alternatively, bleeding from pinholes can be stopped with stitching or gel foam powder. When performing posterior fossa surgery, special care needs to be done when opening above or in the region of sinus transversus, sinus sigmoideus, and torcula. Communication with the anesthesiologist which monitors the TEE is essential, as well as preparation for hemostasis in possible sinus bleeding.

One potential source of venous air embolism during surgery in the posterior fossa is the suboccipital cavernous sinus, specifically the area of the third segment of the vertebral artery, which extends from the transverse foramen of the axis to the dural penetration of the vertebral artery, its loops, branches, supporting fibrous rings, adjacent nerves, and surrounding venous structures [40]. If venous embolism is suspected, the anesthesiologist must immediately inform the neurosurgeon to begin irrigating the surgical field and cover any exposed blood vessels. Oxygen (100%) should be used, and air lodged between the superior vena cava and the right atrium should be aspirated through the central venous catheter. In the case of a massive embolism, advanced resuscitation maneuvers should be quickly initiated and a pneumatic counter-pressure device may be used. An example of this device is MAST, military anti-shock trousers, which extend from the hip to the ankles and are inflated if the patient's condition becomes hypotensive.

Complications due to anesthetic technique include dislodgement of the endotracheal tube. This could be a major complication when oropharyngeal and facial swelling are present (Fig. 9.12). The critical preventive factor is the correct placement and securing of a non-kinking endotracheal tube to prevent an unrecognized disconnection or occlusion. Oral secretions draining from the mouth may loosen the retaining straps, and inadvertent endobronchial intubation may be produced by changes in the head position associated with the turning procedure. The endotracheal tube (ETT) kink during posterior fossa surgery might result from overbending of the softening tube due to oral temperature and neck flexion [41]. The smaller size tubes may be more prone for airway obstruction. It could be difficult to carry out reintubation in such an awful situation when the patient was prone and in pins with surgery in process. Manual straightening of the tube may be helpful to relive kinking of ETT. Emphasis should also be laid on the proper positioning of the head and neck prior to surgery. The use of reinforced, non-kinking ETT may be considered in high-risk patients [42] (Fig. 9.19).

Particular attention should be exercised to prevent a tongue-biting injury by applying one of the forms of protection. The use of the plastic oral airways that place pressure on the posterior

Fig. 9.19 Patient positioned prone with reinforced, non-kinking endotracheal tube

Fig. 9.20 Orofacial swelling following the surgery in prone position

aspect of the tongue results in the edema. Bite blockers that do not extend into the posterior pharynx are recommended. Problems with extubation may occur due to facial edema, swelling of the soft palate, swelling of the tongue causing macroglossia, upper airway edema (because of head flexion and compression of lingual and pharyngeal venous drainage), and swelling of submandibular glands (from compression of the salivary duct) [43]. Proposed mechanism of macroglossia and oropharyngeal swelling 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 (Fig. 9.20). There were two described reports on postoperative macroglossia with swelling in patients with Chiari malformation, one of them being extubated after 3 days on the respirator and the other one requiring emergency tracheotomy to relieve the obstruction, both without long-term sequelae [3, 44–46].

Neuronavigation in the Prone Position

Navigation systems have become essential tools in neurosurgery, and precise registration is indispensable for its accuracy. Rapid and precise registration by surface matching on the facial skin is possible by using the landmarks of the face with the patient supine. On the other hand, incomplete registration may occur in the prone position because of the ventral direction of the face, displacement of the skin by headpins, and obscuring of the skin by the bispectral index monitor, the many electrodes on the forehead, and the eye patch. Surface matching on the occipital scalp may not be suitable for registration because the occipital scalp is flat and is compressed in the supine position during preoperative neuroimaging. To improve accuracy, fiducial markers can be placed prior to magnetic resonance imaging and left in place for neuronavigation registration after positioning.

To overcome the problem of failed registration, Ogiwara and colleagues have developed a method of registration designated as bony surface registration, in which surface matching is achieved by using the bony surface of the skull after exposure. After the skin flap is created and before the craniotomy, bony surface registration is carried out by exposing the skull surface in a sterile environment [47].

In tumor surgery, updated image data allow a reliable identification of a tumor remnant or correction of a catheter position. With the help of intraoperative imaging (intraoperative MRI) navigation data can be updated, so that brain shift can be compensated for and initially missed tumor remnants can be localized reliably [48]. Electromagnetic guided neuronavigation is a recently developed technique which enabled fast and accurate referencing without loss of navigation accuracy despite repositioning of the patient in the semi-sitting position [49]. In the surgery of the posterior fossa, neuronavigation is important tool in localizing the venous sinuses.

Neuromonitoring in the Prone Position

Positioning maneuvers during surgical cases can place the patient at risk for spinal cord and/or peripheral nerve injury. The initial transition of the patient from supine to prone, as well as passive neck flexion or extension, are potentially high-risk portions of the procedure, especially during spine surgery. Intraoperative neurophysiologic monitoring, including transcranial motor evoked potentials (MEPs), somatosensory evoked potentials (SEPs), and electromyography (EMG) can be of use before the initial patient positioning. Their use can facilitate prompt identification of potentially reversible changes that may indicate impending positioning-related injuries [50]. Appropriate mouth gag or bite blocker should be applied when performing MEPs. The use of somatosensory evoked potentials (SSEP) as an indirect indicator of potential injury has been proposed as a useful detector of positioning-related peripheral nerve injury [3]. When performing SSEPs and MEPs, we recommend first to position the patient and then to place the electrodes and afterwards to perform the padding of the hands and feet. The hands and feet should be properly padded while undergoing electrical stimulation in an unparalysed patient.

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