Spinal Procedures in the Prone Position

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Introduction

Spinal surgeries performed through a posterior approach include posterior decompression at any level, thoracolumbar pedicle screw instrumentation and fusions, cervical decompressions and fusions, and many lumbar interbody fusions. While the sitting position can be used for some posterior cervical decompression surgeries such as the foraminotomy, the prone position is used for most posterior spinal surgery given its practicality and ease of approach to the surgical target. However, spinal surgery in a prone position includes various technical considerations and complications of which surgeons must be cognizant. These considerations can vary from one procedure to the next depending on the pathology being treated and the location of the pathology.

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Preoperative Assessment

By virtue of the physiologic impact of placing someone in a prone position, careful consideration must be given to the preoperative assessment of patients. Preoperative assessment should include attention to patient medical comorbidities, body habitus, breast and/or waist size, and length of the procedure. In spinal fractures, one should also consider the nature of the fracture and its stability or instability.

Positioning a patient face-down on the chest for prolonged periods of time requires attention to preexisting pulmonary conditions such as chronic obstructive pulmonary disease (COPD), bronchitis, restrictive pulmonary disease, and rib fractures. Preoperative pulmonary function testing should be considered for patients with significant pulmonary history, especially those with COPD. Similarly patients with significant cardiac history should also undergo a thorough preoperative assessment by a cardiac specialist. Prone positioning has been noted to result in significant hemodynamic and ventilation changes producing decreases in cardiac venous return as well as increases in systemic pulmonary and vascular resistance [1]. Such hemodynamic changes in conjunction with preexisting cardiac or pulmonary disease can significantly impact a patient's status in prone position.

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Patients with spinal cord compression and/or myelopathy must be carefully assessed for their ability to assume desired surgical position without becoming further symptomatic prior to surgery. Preoperative assessment for such patients should include an examination of the patient as they carefully and slowly extend their neck to determine whether any worsening of their condition or new symptomology is produced. If any degree of extension does produce new or worsening symptoms, then it is a clear indication that such maneuvers should be avoided during the intubation and anesthesia process. Specific considerations revolving around positioning with unstable fractures or severe spinal cord compression will be covered in a later section, when positioning in the setting of specific pathologies is discussed.

Fig. 13.1 A Wilson frame is placed on a Jackson table. The Wilson is covered with a bed sheet to protect the patient's skin and also to facilitate easier manipulation of the patient by utilizing the sheet to lift and adjust the patient's body

The Full Prone Position

Preparations

The ability of the cervical spine to sustain the manipulation necessary for laryngoscopy and intubation as well as the ability of the spine to sustain turning, all under conditions of muscle relaxation, should be clearly understood by all members of the surgical team.

After induction of general anesthesia and intubation steps are taken to ensure a safe and successful transfer of the patient from a supine position on the hospital bed to a prone position on the operative table. For preparation of the operating room table, we place a covering or bed sheets over the padding of the table. For Jackson tables in an open configuration, the chest, pelvic, and knee supports should be appropriately covered typically with pre-fit covers for the chest and pelvic pads and foam pads for the knee support plate. For Jackson tables in a closed or flat-top configuration or with other "closed" operative tables that do not allow the abdomen to hang free, prone position surgery will require either chest rolls or a support frame, typically a Wilson frame. Chest rolls may be conventionally available gel rolls or they can be constructed from blankets or sheets that are tightly rolled and secured with tape. The advantage of chest rolls constructed in this method is that they can be customized for the patient in both length and girth. When a Wilson frame is used, it should be covered with a bed sheet or other covering typically with generous overhang so as to allow operating room staff and surgeons to utilize this for manipulation of the patient's body after turning to a prone position (Fig. 13.1). If bed attachments are required for self-retaining or tubular retractions systems or other devices, these should be evaluated prior to draping and also evaluated to ensure that placement does not interfere with fluoroscopy.

If the surgical case may require rapid volume repletion, blood product transfusion, close arterial pressure monitoring, or close volume status monitoring, then appropriate catheters for central venous or arterial access should be placed prior to turning into the prone position. Similarly, leads for neurophysiologic monitoring should also be placed prior to turning the patient. All electrocardiogram (EKG) leads must be removed from the chest, or any place where they could end up compressed between the table support system and the skin or contribute to artifact on the X-ray once the patient is prone. Foley catheters should be placed prior to prone positioning, in cases that are anticipated to take longer than 2 h.

Sequential compression devices should be employed routinely and activated prior to induction of general anesthesia.

If a cervical spinal procedure is to be performed, the patient will most likely require placement of the Mayfield three-pronged head holder prior to turning. For adults, we utilize 50–60 pounds of force for the head clamp—more force can be used, but should never exceed 80 pounds. Prior to placing the head holder on the patient, the surgeon must ensure that the patient is adequately anesthetized to avoid significant changes in vital signs such a sudden increase in blood pressure or heart rate. The surgeon should always assess the Mayfield bed attachment as well, ensuring that it is securely attached to bed prior to turning the patient.

Types of Tables

Standard operative tables, such as the Mizuho Skytron table, do not provide an opening to allow the abdomen to hang freely, are the most commonly utilized operative tables. In prone position spinal surgery, these standard beds are often utilized for posterior cervical procedures and lumbar decompression or discectomies. These tables are not ideal for fusion procedures where the pedicles and other specific bony anatomy must be visualized in an anterior-posterior fluoroscopy view, as the bed construct is not radiolucent and significant obstructions will be encountered on intraoperative fluoroscopy—such as the pedestal in the middle of the table. When utilized for cervical procedures, the bed is often prepared with chest rolls as mentioned previously and three-pronged head holders such as the Mayfield head holder. One beneficial aspect of certain Skytron tables is the ability to slide the table surface either toward the head or feet. This improves ease of C-arm fluoroscopy positioning by allowing manipulation of the level of interest away from the table pedestal. It is always important to ensure that the table surface is positioned appropriately with regard to the table base which can impede C-arm movement.

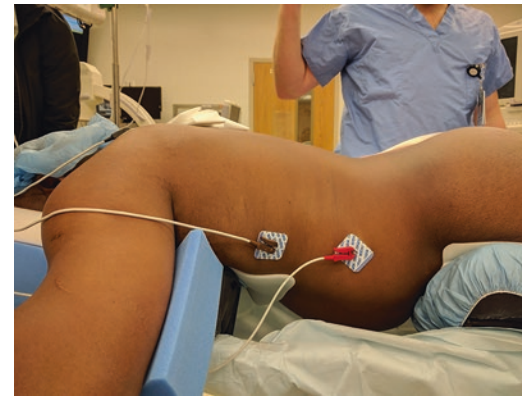

Fig. 13.2 An open configuration of Jackson frame allows the patient's abdomen to hang free assisting in reducing intra-abdominal pressure and in turn helps reduce venous pressure and bleeding

Fusion procedures in the prone position benefit from utilization of the Jackson operative table. The Jackson table is fashioned in one of two configurations for prone position spinal surgery. An "open" configuration allows the patient's abdomen to hang free without compression, reducing intra-abdominal pressure, which in turn reduces venous pressure in the thoracolumbar region allowing for reduced venous bleeding during the procedure (Fig. 13.2). This configuration is typically favored for transforaminal lumbar interbody fusions (TLIFs), posterior lumbar interbody fusions (PLIFs), and thoracolumbar pedicle screw fixations. The open configuration allows for natural lumbar lordosis, which is useful when the goal is fusion of the thoracolumbar spine in a natural alignment. The Jackson table is radiolucent allowing for unobscured fluoroscopy and anteroposterior imaging during instrumentation and interbody graft placement for thoracolumbar fusion procedures.

A "closed" or "flat-top" configuration is also utilized for thoracolumbar fusion procedures, especially where interbody placement is not required. Furthermore, it is often preferred in the setting of unstable thoracolumbar fractures where the additional abdominal freedom and consequent lack of support of an open configuration may result in worsening of the fracture. It serves to provide similar benefits in terms of radiolucency

of the frame. When utilizing the Jackson table, one should always consider the position of the table ends which are adjustable and permit a change in the overall table height as well as allowing either a Trendelenburg or reverse-Trendelenburg positioning. There is a pin in place, holding each end of the table at its set height, and it should be confirmed that these pins are set appropriately prior to transferring the patient to the table (Fig. 13.3). For patient safety, these ends must be adjusted prior to transferring the patient to the table.

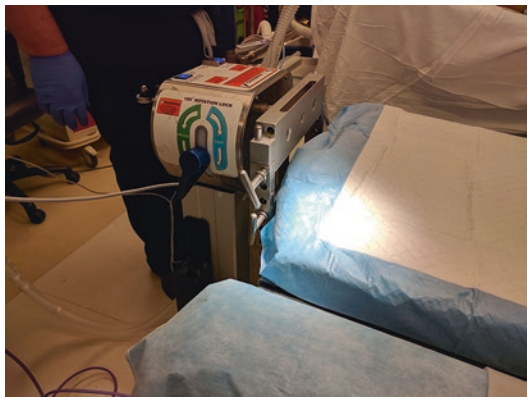

Fig. 13.3 Jackson tables can be adjusted as needed for either Trendelenburg or reverse-Trendelenburg by adjusting the large pins at the head and tail end of the table. Such adjustments must be done prior to transferring the patient to the table

The Wilson frame, the frame most commonly used by present authors, is radiolucent and when coupled with a closed Jackson table allows for unobscured fluoroscopy in both anteroposterior and lateral views. Wilson frames comprise two parallel bolster pads which can be widened or narrowed and are adjustable typically by a crank on the side of the frame which allows the arch of the pads to be raised or lowered. This manipulation of the pads is designed to allow the surgeon to alter the patient's sagittal lumbar alignment as desired for a procedure [2] (Fig. 13.4). In the setting of lumbar decompression and discectomy procedures, the Wilson frame is often utilized to allow for flexion of the torso and abdomen, increasing sagittal flexion of the lumbar spine, splaying the lamina, and enlarging the interlaminar operative corridor for these procedures. Care should be taken if any fusion procedure is done with the Wilson frame, as the same properties that are advantageous for decompression can cause problems with fusion. If instrumentation is performed with

Fig. 13.4 The Wilson frame is seen here on a Jackson table. The Wilson frame comprises two parallel bolster pads which can be adjusted by utilizing the crank shaft on the side of the frame which allows the pads to be raised or lowered in effect allowing the surgeon to alter the patient's sagittal alignment as needed

Fig. 13.5 The patient is being prepared to turn to a prone position on a Wilson frame. Note that the foam facial/head rest has already been placed on the face with the endotracheal tube within the designated recess (arrow). The patient's iliac crest should line up with the center of the Wilson frame for optimal positioning (dotted line)

the Wilson framed raised, it can cause fusion in a "flat back" alignment, with loss of the lumbar lordosis. Use of the Wilson frame has been associated with decreased cardiac output and reduced venous return with resulting effects on hemodynamics in prone position spinal procedures [3].

Turning the Patient Prone

After adequate preparations have been made for the patient to be turned prone on the selected operative table, careful cooperation is required for the actual act of turning the patient prone from a supine position. Turning the patient requires at least four people. It is recommended that at least two team members assist with the patient torso, one to push and turn and the other to catch the patient on the side of the operative table. A third person, generally the anesthetist, controls the patient's head. If the patient has an unstable cervical fracture, or if the patient's head is in pins, it is preferred that a surgeon control the head. A fourth member of the team should help with the patient's legs while positioning. All lines and catheters must be carefully prepared and transferred throughout this process. The endotracheal tube, once secured to the patient, must be disconnected during the turning process.

When the table is prepared as above, the team must level the hospital bed slightly higher than the operating table. The patient or bed should be slid so that the patient's chest is slightly closer to the head of the operating table than the chest pad or chest roll. The patient will travel a decent distance while being rolled prone, but if they are far from the operating table, they should be slid toward the table before rolling. When utilizing a Wilson frame or hip padding on an operative table, ensure that the patient iliac crest will line up with the center or apex of the frame and the superior aspect of the pad (Fig. 13.5). Often, a pad should be placed between the patient's arm and the frame of the operating table to avoid cutaneous injury during the flip. Elderly patients are at highest risk for these problems, such as degloving injuries.

Once everything is prepared, the team member responsible for the patient's head counts down before the turn. In this way, the patient's head, torso, and legs can be turned as a single unit. The team member responsible for catching the patient's torso should do so with one or both arms under the patient. This makes it easier to reposition the patient as needed. To help the surgical team avoid back injury, the operating table should be high enough so that the team members do not need to stoop over while positioning the patient. Extra lifting help should always be called for when positioning large patients.

Once turned onto the operative table, any adjustments that are necessary should only be

made once all catheters are secured, the patient limbs and genitalia are safe, and the anesthetist has communicated continued control of the endotracheal tube.

Full Prone Position

One should ensure that breasts are positioned medially and/or inferiorly with the nipples free of compression when positioned on a Wilson frame or chest rolls. Patients with large or procedurally augmented breasts may pose a challenge for positioning and one should consider wide-based frames or chest rolls to accommodate large breasts. Foam padding should be utilized when necessary to ensure that any breast or abdominal tissue hanging laterally is appropriately protected from the bed frame. Similarly, the patient genitalia should be inspected to ensure that they are free of any compression. It is particularly important to ensure that both testicles and penis are free of compression when positioning male patients. Take care to ensure that the penis is hanging free with the testicles and is not compressed between a frame or table and the patient's leg. When the genitalia are in close vicinity to the bed frame, the temptation exists to place foam between the frame and the patient's anatomy. Care should be taken to be sure that this foam does not introduce a compression that did not previously exist. Generally, if there is no contact between the anatomy and the frame, foam is not required.

The arms are then positioned according to the procedure being performed and are typically placed inferiorly or superiorly on arm boards in a prone-surrender or "superman" configuration (Fig. 13.6) or are tucked to the patient's side. The use of oversized hip pads for a thin patient will sometimes allow the arms to be tucked to the sides, supported by the excess hip pads, even when using an open Jackson table. Foam padding is utilized under the arms where they contact the arm boards or table frame. If the arms are positioned superiorly on arm boards, they should appear relaxed and should not be abducted greater than 90° or overextended, as this has been associated with increased risk for brachial plexus injury [4]. Arms should be padded at the elbow to protect the ulnar nerve on the medial aspect, and also at the hand to keep the hand in a safety position as much as possible (Fig. 13.7). The axilla should be free of any compression. If it appears that the shoulder is unsupported or is coming in contact with the table frame, care should be taken to pad the shoulder and not place padding up into the axilla.

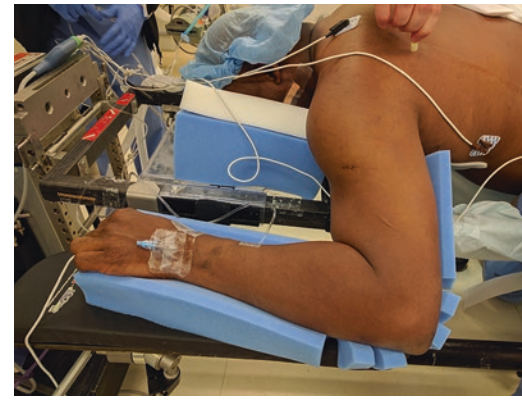

Fig. 13.6 The patient is placed in a prone position for a lumbar spinal procedure with his arms in a "superman" or prone-surrender position on arm boards. Foam padding is utilized to protect the skin and peripheral nerves

The head is placed into a foam head rest (face pillow) if a three-pronged head holder is not utilized. Often the foam head rest or face pillow will be placed over the patient's face prior to turning as it will allow from proper fitting of the facial structures and endotracheal tube and minimize head and neck manipulation once the patient has been turned to the prone position (Fig. 13.5). The patient's neck should be maintained in a neutral position and free of compression anteriorly while in the foam head rest with care taken not to overextend the neck. Significant flexion of the neck should also be avoided when possible as this can create problems to venous return, ventilation, as well resulting in decreased blood flow to the brain and spine due to effects on carotid and vertebral arteries [2].

The patient's chin should be inspected to ensure that it is free of constant external pressure or contact. The head and face must carefully be inspected as well to ensure that there is no compression of the nose, eyes, or other facial elements.

Fig. 13.7 The patient is placed prone on an open configuration Jackson table with arms in a "superman" or prone-surrender position. It is important to ensure that the arms are in a relaxed position and not overextended or abducted greater than 90°. Again foam padding should be utilized to protect the soft tissue from pressure injury and also the peripheral nerves, especially the ulnar nerve. Note that the axilla is also padded with foam to protect the brachial plexus

The lips and tongue must be inspected to ensure that they endure no compression, especially by the endotracheal tube, as the lips or the tongue can be pinched between the endotracheal tube and the teeth. A bite block is utilized to avoid pressure injury to the tongue when necessary. The patient's eyes should be taped closed with clear, thin tape or Tegaderm™ to protect the eyes from direct injury such as corneal abrasions or lacerations and from the possibility of chemical injury from skin sterilization agents. Alcohol and chlorhexidine gluconate will both cause corneal scarring and opacification if they reach the eye, but even detergents in scrub solutions can be problematic for the eye.

For all prone position surgeries, it is very important to ensure that the patient's eyes are completely free from any external pressure. Additionally, the patient's head should ideally be elevated above the level of the heart in an effort to prevent increased intracranial pressure and also increase intraocular pressure, which may rarely lead to ischemic injury and blindness. One advantage of placing the head in pins is to avoid ocular pressure, and one may consider utilizing the Mayfield even for lumbar cases for this reason. Although, there are studies that suggest that the complication of blindness in prone position surgery is as common in the setting of significant blood loss and low blood pressure as it is in the setting of direct compression of the globe [5, 6].

Foam or other padding is required where the knees contact the table. Knees should be flexed and the shins padded so that the toes are not under contact pressure. The patient's body should then be carefully secured to the operative table with straps extending across the torso when possible and also across the buttocks, ideally in a slight cranio-caudal direction as a sling-like support should the patient need to be put into a significant reverse-Trendelenburg position (Fig. 13.8). Foam padding is placed between the patient and the strap to protect the skin from direct compression by the straps and to keep the strap edges from cutting into the skin.

Cervical Spine Procedures in Prone Position

Spinal pathology for prone position surgery can be categorized as either degenerative, infectious, neoplastic, or traumatic. Although some of these pathologies may be glacially unstable, here we

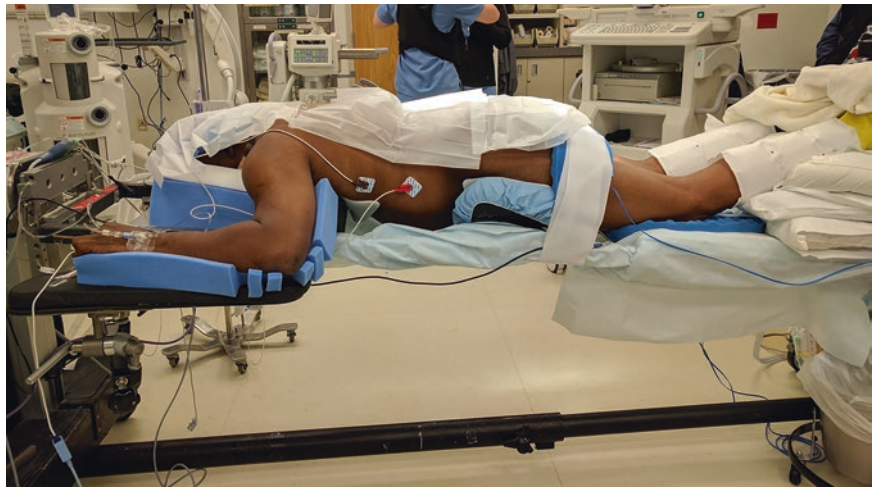

Fig. 13.8 The patient is positioned prone on an open configuration Jackson table. All pressure points are padded appropriately with foam padding. Note that the table is arranged in a reverse-Trendelenburg position by adjusting the head of the Jackson table (blue arrow). Also note that the patient has a padded strap placed around the buttock in a cranio-caudal direction as a sling-like support (yellow arrow). The patient's legs and feet are kept slightly elevated with pillows

will group degenerative, infectious, and neoplastic stable pathologies to describe considerations specific to this group with regard to prone positioning of the patient. Prone positioning for traumatic spinal fractures will be described for special considerations differentiating unstable and stable fractures.

Posterior cervical spinal procedures for degenerative pathology include cervical foraminotomies, laminectomies, and instrumentation and fusion procedures such as subaxial fusion, C1–2 fusion, and occipito-cervical fusion. Infectious pathologies that may require surgical intervention from a posterior approach include epidural infections and osteomyelitis causing deformity or instability. Neoplastic pathology in the cervical spine requiring prone positioning includes posteriorly located primary tumors of the neuraxis or axial skeleton, metastatic disease involving the cervical spine, and even anteriorly located pathology if the surgical goal is only posterior decompression. Neoplastic lesions may also result in instability requiring posterior fixation; however, positioning considerations for unstable pathologic fractures of both neoplastic and infectious etiology will be discussed more in depth later, in the section reviewing positioning management for unstable cervical fractures.

In patients with significant cord compression and acute myelopathy, every effort should be made to minimize extension of the patient's neck and keep the patient as neutral as possible. Awake, fiber-optic intubation may be the best option as it will allow for clinical assessment of the patient during and after intubation. Myelopathic patients are overall best served to have their necks kept inline and neutral during the intubation process with minimal manipulation. If the patient is examined preoperatively and has new symptoms with neck extension, then great care must be taken in the operating room with intubation and positioning. The surgeon should always be present to help keep the cervical spine held manually in a neutral position during the intubation process in such a setting.

A preoperative discussion between anesthesia and the surgeon should include the use of neurophysiologic monitoring, presence of myelopathy, and desired blood pressure parameters. Volatile anesthetics will suppress sensory evoked potentials to varying degrees and full paralytic dosing will cause loss of motor evoked potentials.

Maintaining mean arterial pressures greater than 85 mmHg has been thought to be related to improved outcomes in spinal cord injury patients [3]. Attempting to reduce epidural venous bleeding and ocular pressure by lowering venous pressure with reverse-Trendelenburg positioning can also impact venous return to the heart and arterial blood pressure causing hypotension and consequently reducing spinal cord perfusion [2, 7]. The surgeon should speak with anesthesia about anticipating such a drop in blood pressure when positioning for maximal venous drainage and the team must appropriately correct the arterial blood pressure according to the goals that have been set. Such considerations are particularly important in patients that are suffering from *acute* myelopathy.

Degenerative, neoplastic, and infectious cervical spine procedures are typically performed utilizing either a Skytron adjustable operative table or Jackson table. The latter is beneficial in cases involving the lower cervical or upper thoracic spine, or in patients with short or stout necks, where fluoroscopy could be challenging. The Jackson table is also preferred in any case requiring anteroposterior fluoroscopy. Most posterior cervical cases are best positioned with Mayfield Infinity three-pronged skull clamp system with appropriate table attachment—placement of the head clamp has been covered previously in the preparations section. Patients are typical placed neutral (fusions/instrumentation) or slightly flexed (decompression/foraminotomy) when no central compression or myelopathy is present (Fig. 13.9). Care must be taken to keep patients neutral while actively transferring them from a supine position to the prone position.

Patients in the prone position on a Skytron table are placed on chest rolls, detailed above in the preparations section. If the patient is flexed in pins, the surgeon must inspect the patient's chin to be sure that it does not contact the table. Arms should be secured to the patient's side and tucked with all pressure points appropriately padded as described previously. If done on a Jackson table, the arms boards should be down at the patient's sides. Fluoroscopy should be brought in at this point for lateral fluoroscopy if it is needed and assess whether shoulder taping will be required to achieve sufficient lateral X-rays for the procedure. If shoulder taping is required, one must ensure that the tape does not involve any electrical leads or anesthesia lines. One should also avoid considerable posterior retraction of the shoulder or overly retracting the shoulder inferiorly as this may result in an injury to the upper trunk of the brachial plexus. When using a Jackson table, we place the head of the bed in one of the top three slots and the foot of the bed in the bottom slot prior to placing the patient on the bed to allow for a degree of reverse Trendelenburg. Regardless of the bed type, most posterior cervical procedures should be performed with the patient head above the level of the heart (reverse Trendelenburg) to provide a more physiologic state for the patient, better visualization in the operative field, reduced venous pressure and venous bleeding, and reduced intraocular pressure which can notably increase with prone positioning [8]. Arterial pressure changes must be accounted for and corrected appropriately when specific blood pressure parameters are required.

If neurophysiologic monitoring is to be utilized, this should be placed prior to positioning the patient prone. Pre- and post-positional SSEPs/MEPs should be performed to ensure that positioning has not created a significant change.

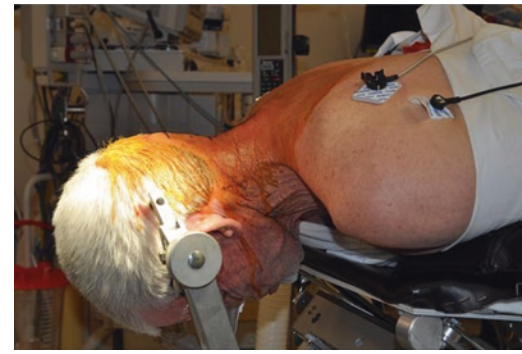

Fig. 13.9 Posterior cervical spinal procedures are often done utilizing the Mayfield three-pronged skull clamp for positioning. As seen here, it is important to keep the patient's neck in a neutral position or slightly flexed depending on the pathology being treated. Here, the patient is placed on a Skytron operative table on chest rolls with arms padded and tucked to the side

Care must be taken when utilizing neurophysiologic monitoring as intermittent stimulation can result in movement and twitching of arms and legs. As such, arms and legs must be secured well in anticipation of such movement. Furthermore, the tongue and lips must carefully be padded and protected typically with a bite block in place to keep stimulated contraction from resulting in bite-related injury.

Unstable Cervical Pathology

For cervical fractures deemed unstable, it should be communicated to the anesthetist that the patient have minimal manipulation of the neck during intubation. Consideration should be given to fiber-optic intubation, potentially with the patient awake to allow pre- and post-intubation neurologic examination. Patient transfer should occur with the patient's cervical spine supported with a rigid collar such as Miami J or Aspen and maintained in a neutral position with minimal manipulation. If the collar needs to be removed, the surgeon should be at the bedside to assist in keeping the neck supported and neutral. If the patient is positioned with a collar in place, it can be removed after the patient's head is fixed in the three-pronged head holder or in traction if appropriate. Patients with unstable pathology and spinal cord compression should also have strictly maintained blood pressure parameters throughout positioning and the procedure.

Often in the setting of fracture dislocations, manual reduction is needed to successfully reduce fractured vertebrae from an abnormal position prior to fixation. Surgeon, anesthetist, and OR staff should have a clear discussion about this prior to surgery and the steps involved for such a maneuver should be clearly outlined so that all parties are prepared for this stage of the procedure. When this is necessary, the primary surgeon or an assistant surgeon should be in charge of manipulation of the neck for reduction of the fracture. Such a reduction of a fracture or locked/perched facet joints is typically achieved by carefully releasing the Mayfield joints under the drapes to allow manual manipulation of the neck by the physician under continuous fluoroscopy at the appropriate stage of the surgery. Once the reduction maneuver has been accomplished, the Mayfield must be carefully tightened and secured again.

Thoracic and Lumbar Procedures in Prone Position

Thoracic and lumbar surgeries performed in the prone position include thoracic or lumbar laminectomies, lumbar foraminotomies, lumbar or thoracic discectomies, and thoracic and lumbar fusions—most often for degenerative pathologies. Other pathologies include neoplastic and infectious pathologies—osteomyelitis, discitis, and various bony or spinal neoplasms. Additionally, spinal deformity cases are performed either partially or entirely in the prone position.

Decompressive spinal procedures comprise the majority of spinal procedures in this region of the body. Patients are typically placed prone on a flat-top Jackson table or Skytron adjustable table often with a Wilson frame. For a purely decompressive surgery, the table choice is not critical although the Wilson frame, as described previously, allows for some flexion in the thoracolumbar region, essentially widening the corridor for decompression and providing better visualization for the operation. It must be noted that if AP fluoroscopic views are needed (such as with fusion or sometimes with foraminotomies), the Skytron bed is not typically radiolucent and may obscure AP X-ray images.

All pressure points are padded appropriately with foam padding. For thoracolumbar procedures, the arms will be positioned superiorly on arm boards as detailed in the full prone section. For patients with rotator cuff problems, the shoulders may not have full range of motion and the arm boards must be adjusted to accommodate for the patient's joints. Foam padding protects the knees from pressure, and pillows under the lower legs flex the knees and keep the toes from surface contact.

Lateral fluoroscopy can be brought into the field to ensure that adequate X-ray imaging can

be achieved for localization given the current position. Spinal needle or blunt instrument localization should be performed as per usual to identify the appropriate level. As in posterior cervical cases, the head should ideally be kept slightly elevated if possible, especially for longer cases to avoid ocular pressure-related injuries. The abdomen should be kept free of significant compression to reduce venous congestion and bleeding. The breasts should be free of nipple compression and generally positioned down and in, relative to the chest pad or chest roll.

For patients requiring thoracolumbar instrumentation and fusion procedures such as pedicle screw fixation, transforaminal lumbar interbody fusions (TLIFs), or posterior lumbar interbody fusions (PLIFs), similar principles for prone positioning are utilized with some adjustments to assist with better visualization during fluoroscopy. For most fusion procedures, the radiolucent Jackson table typically in an open configuration is best as it allows for unimpeded visualization of bony anatomy on X-ray. As visualization of pedicles, interspaces, and vertebral body landmarks is crucial to adequate placement of instrumentation, fluoroscopy or another imaging modality is key to a successful spinal instrumentation or fusion case.

Always ensure that any wires, cables, tubing, or leads are not obstructing optimal visualization of necessary bony anatomy on fluoroscopy. In this sense, it is encouraged that the surgeon check both anteroposterior and lateral views of the work area to ensure that no significant alterations are needed to patient positioning or to remove obstructions prior to sterile draping. It is ideal for the fluoroscopy unit (typically C-arm) to be brought into the field and draped prior to incision and positioned either cranially out of the area of the operative incision or caudally distal to the surgical tech and mayo stand. If positioned cranially in the field, care must be taken to ensure that the patient's arms are free of contact with the machine, which rarely can be the source of peripheral nerve or myocutaneous injuries.

Spinal deformity correction cases are quite extensive, spanning multiple spinal levels, and requiring several hours of operative time. Given the degree of muscle dissection and bone drilling in deformity surgeries, one should expect and be prepared for significant blood loss and volume shifts. Such patients should be prepared with appropriate monitoring and IV access. Clear hemodynamic parameters should be set with blood products readily available. Special attention should be given in these cases to patient pressure points, face, eyes, breast, arms, and other potential sources of complications given the typical length of these procedures.

Unstable Thoracic or Lumbar Pathology

With unstable fractures of the thoracic or lumbar spine, care should be taken to avoid manipulation of the patient. These patients should be maintained flat unless otherwise indicated and controlled techniques should be utilized when patient transfer or manipulation is needed. Jackson frames in an open configuration should rarely be utilized in unstable fractures or pathology of the thoracic or lumbar spine as the absence of adequate abdominal support may exacerbate any displacement in the setting of instability. A closed or flat-top Jackson table is typically preferred for cases involving unstable thoracolumbar spine fractures. Chest rolls are utilized on these tables, and this allows for adequate patient support and radiolucency for imaging while avoiding overextension.

Conventional manual log-rolling techniques have thought to be the best suited for prone positioning of the unstable thoracolumbar spinal patient; however, recent cadaver studies have indicated that the utilizing a Jackson table-turn technique for prone positioning significantly reduces rotational and translational forces that could potentially worsen a fracture [9]. This technique involves the use of a Jackson table attachment which can allow for another table surface to be secured, and effectively "sandwiches" a patient securely between the two table surfaces. In this fashion, the patient is supine initially on the first Jackson table surface then the subsequent surface to be utilized for prone positioning is

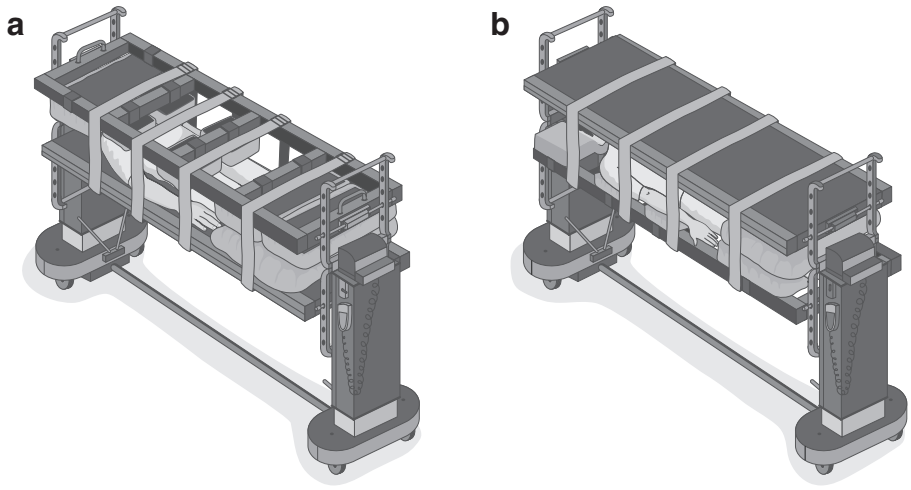

Fig. 13.10 The Jackson table sandwich technique requires a second table surface to be placed on top of the supine patient. After properly securing the patient (**a**) the bed can be rotated so that the patient becomes prone and the original table surface can be taken away (**b**)

secured above the patient carefully after the patient has been strapped into the first bed. The entire table is then rotated maintaining the patient rigidly fixed between the two table surfaces and allowing for minimal rotational or translational forces on the patient. Once rotated, the first bed utilized for supine positioning is removed leaving the patient prone on the second bed attached to the Jackson table frame (Fig. 13.10).

Special Considerations for Navigated Instrumentation

When using navigation that requires an intraoperative CT scan, the machine needs to be able to close around the patient. For fluoroscopy-based navigation, positioning is as it would be for instrumentation with live fluoroscopy.

Navigated instrumentation requires a radiolucent table. Thoracolumbar instrumentation is generally performed on an open configuration Jackson table for the sake of natural lumbar alignment in lordosis. This table is radiolucent and meets another requirement of navigated instrumentation—it lacks a pedestal in the middle of the table.

Placing the patient in the Mayfield three-pronged pins for head fixation causes additional concern, as the Mayfield connection extends below the normal table surface and is also quite wide. Again, for thoracolumbar fusions, this is not an issue, but for C1–2 fusions it can become difficult to close the intraoperative CT scanner around the patient. In this case, the Mayfield needs to be arranged so that inferior protrusion from the table is as little as possible, or a low-profile Mayfield adaptor needs to be used. Additionally, a radiolucent construct is available for the Mayfield head fixation system that can be utilized to avoid obstruction during radiography.

The patient's arms present the same concern that they must not be protruding in a way to block the CT scanner from closing. Generally, this does not require any change in positioning. If the arms are positioned so that the surgeon will be comfortable operating on the levels of interest, the CT scanner will also be able to close around those levels. For example, the patient's arms would be positioned up for a lower thoracolumbar fusion, but they would be positioned down for an upper thoracic fusion. Still, the scanner is broad, and care needs to be taken that it is not hitting against the arm boards when being brought in and out. In all cases, the navigation camera is traditionally positioned at the foot of the operative table.

Complications

Visual Complications

Visual complications following prone positioning were first reported in 1948, when a patient positioned improperly on a Bailey headrest suffered postoperative blindness [10]. Visual loss in the setting of spine surgery can occur at a rate ranging from 0.019 to 0.2% with higher rates seen in prone position surgery [11–13]. Risk factors described to be associated with higher rates of perioperative visual complications include diabetes mellitus, coagulopathy, neurologic disorders, and paralysis [11]. In general, ischemic optic neuropathy (ION) is described as the most common cause of visual loss postoperatively with up to 89% of such cases being attributed to this etiology [14]. Prone position surgery subjects patients to various factors that increase the risk for ION postoperatively. These risk factors include, often in combination, intraocular venous pressure, extensive blood loss (typically greater than 4 L), and hypotension intraoperatively [15]. Many of these risk factors can be avoided with careful attention during positioning and vigilance intraoperatively. Ischemic optic neuropathy may result in permanent visual loss; however, there may be some benefit obtained by utilizing corticosteroid therapy [16].

Central retinal artery occlusion is seen in this patient population in the setting of prolonged direct compression of the eye(s) resulting in increased intraocular pressure and thus reduced retinal perfusion, it can also occur from thromboembolic events in the perioperative period [17]. Avoiding pressure on the globes by ensuring patients' eyes are free if utilizing horseshoe headrests or even foam headrests can reduce the risk of this potential cause of visual loss. Immobilizing the head in a Mayfield can eliminate any direct pressure on the globes and thus significantly reducing this risk of potential postoperative complication. Cortical blindness as a result of ischemic damage to the visual cortex is another, albeit rare, complication of prone surgery that can result in postoperative visual loss. It is more commonly seen in deformity spinal surgery and procedures involving spinal fusion [11]. Typically, patients will improve over time, but complete recovery is rare [18]. Active monitoring and careful management of blood pressure as well as minimizing blood loss when possible will help reduce the risk of this rare complication.

Corneal abrasion are also possible in prone position spine surgery and are the most common eye complication amongst all spine surgeries [17]. General anesthesia can result in decreasing natural lubrication of the eye and, in combination with incomplete eye closure, can result in corneal abrasions. These are typically self-limiting but require postoperative ophthalmologic evaluation [17]. Adequate eye closure and protection with specialized goggles or Tegaderm™ after lubrication of the eyes after induction of anesthesia can help prevent such ocular injuries.

Peripheral Nerve and Brachial Plexus Injuries

Brachial plexus injuries, although rare, are known complications when performing prone position surgeries. The plexus courses over multiple bony structures such as the clavicle and the humeral head and in this course can be unintentionally stretched or compressed, risking injury to the nerves that can manifest as arm weakness and/or sensory deficits. Risk factors that increase the risk of such injury include diabetes mellitus, hypovolemia, and alcoholism [4]. When positioning prone, the most important factor to consider to prevent brachial plexus injury is the degree of abduction of the arms as they are placed on arm boards. Abduction at the shoulder greater than 90° puts the patient at risk of a lower trunk injury [4]. Aggressive taping of the shoulders with downward traction puts the patient at risk of an upper trunk injury. Significant extension and external rotation of the arm should be avoided as well as these arm positions have been associated with increased risk for brachial plexus injury—the elbows should be positioned below the level of the shoulders and the hands should be even with the elbows or lower [4]. The arms should be positioned in a relaxed nature on arm boards with

appropriate ulnar and wrist padding and the axilla should be free and open. One retrospective review suggested that the prone-surrender or superman position with arm on arm boards superiorly was significantly higher risk for impending upper extremity nerve injury when compared to arms tucked at the patient side [19]. As such, it would be prudent to treat these cases as high risk for peripheral nerve injury for upper extremities and any neurophysiologic changes that are not corrected with conventional measures should be evaluated for repositioning maneuvers of the arms.

Ulnar nerve injuries have been reported in the setting of prone position spinal surgery and can be due to a variety of causes. The most commonly known sources of ulnar nerve injury are direct external compression of the nerve as it passes the cubital tunnel, malposition of the blood pressure cuff, excessive elbow flexion (>90°), or an arm falling off an arm board [4]. Obesity has also been described to be associated with increased risk for ulnar nerve injury in the setting of prone positioning [20].

Similar to ulnar neuropathy due to malpositioning, lateral femoral cutaneous nerves can also be injured if not properly cushioned or if the leg is inappropriately positioned. These patients can develop meralgia paresthetica resulting in pain and paresthesia of the anterior and lateral thigh. Direct external compression of the lateral femoral cutaneous nerve is usually the cause and such compression is more likely when pelvic bolsters are used for positioning, with such compression occurring in up to 24% of patients undergoing prone position spinal surgery [21].

Myocutaneous Complications

Myocutaneous complications are some of the most frequently encountered complications of prone position surgery [2]. They can occur from varied causes such as IV infiltration, cutaneous pressure over the course of a long procedure, or acute injury during the act of positioning. If an IV infiltrates while running a pressor or hypertonic solution, there is risk of damage to the limb. Pharmacy should be contacted to see if there is an antidote to be administered based on the solution that infiltrated. Also, plastic surgery consultation may be required if there is significant skin necrosis.

Plastic surgery consultation may also be required in the event of a degloving injury. When this occurs, it is usually caused during the positioning at the beginning of the case, or while positioning the patient back to supine on the hospital bed at the conclusion of the surgery. This can be avoided with proper foam padding under the downside arm during the flip to avoid direct contact to the bed frame. It is more common in elderly patients and patients taking long-term steroids, due to thinned skin.

Cutaneous injuries sustained from prolonged prone positioning are usually over the chest, hips, or knees, where the patient's weight is most concentrated on the padding. At the end of the case, these areas are likely to be red. If the skin blanches appropriately, the skin will not likely have any serious injury. If it does not blanch, or if it shows signs of blistering, it will need careful attention in the coming days and may require a skin care consult to optimize healing.

Pressure sores to breasts are also not uncommon, and female patients being positioned prone should always have their breasts carefully inspected and secured at the time of positioning. Patient with larger breasts obviously are at greater risk for such complications. Patients with a history of breast augmentation and implants can rarely develop rupture of their implants from prolonged prone positioning possibly resulting in breast necrosis [22].

Pressure-related injury to the head and neck are of concern for prone position surgery, and this risk increases with the length of the surgery as well as with volume replacement which can cause facial edema [23]. Appropriate use of padded headrests such as the ProneView® protective helmet system as well as elevation of the head has been shown to reduce the risk of pressure-related injury to the face [23, 24]. Use of the Mayfield three-pronged clamp has been described and utilized by surgeons to avoid pressure sores and cutaneous complications of the face [25].

Compartment syndromes in the setting of prone position surgery are quite rare. There are reports of lumbar spinal surgery being complicated by anterior thigh and tibial region compartment syndromes resulting in muscle necrosis and requiring fasciotomies in certain cases due to vascular compromise [26–28]. Factors that have been reported to increase the risk of limb compartment syndrome include muscular habitus, obesity, and lengthy surgical procedures [29]. Rhabdomyolysis can also occur in prone position surgery, often accompanying compartment syndromes, but can also rarely occur without any clear evidence of limb ischemia or external signs of compression such as skin changes [30]. In such cases, secondary injury due to myoglobinemia and myoglobinuria, especially renal injury, can occur and thus management must be appropriately tailored.

References

1. Toyota S, Amaki Y. Hemodynamic evaluation of the prone position by transesophageal echocardiography. J Clin Anesth. 1998;10:32–5.
2. Rozet I, Vavilala MS. Risks and benefits of patient positioning during neurosurgical care. Anesthesiol Clin. 2007;25(3):631–53, x.
3. Hadley MN, Walters BC, Grabb PA, Oyesiku NM, Pryzbylski GJ, Resnick DK, et al. Guidelines for the management of acute cervical spine and spinal cord injuries. Neurosurgery. 2002;50(Suppl 3):S1–S199.
4. Uribe JS, Kolla J, Omar H, Dakwar E, Abel N, Mangar D, et al. Brachial plexus injury following spinal surgery. J Neurosurg Spine. 2010;13:552–8.
5. Brown RH, Schauble JF, Miller NR. Anemia and hypotension as contributors to perioperative loss of vision. Anesthesiology. 1994;80:222–6.
6. American Society of Anesthesiologists Task Force on Perioperative Blindness. 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.
7. Yokoyama M, Ueda W, Hirakawa M, Yamamoto H. Hemodynamic effect of the prone position during anesthesia. Acta Anaesthesiol Scand. 1991;35:741–4.
8. Carey TW, Shaw KA, Weber ML, DeVine JG. Effect of the degree of reverse Trendelenburg position on intraocular pressure during prone spine surgery: a randomized controlled trial. Spine J. 2014;14:2118–26.
9. Prasarn ML, Zhou H, Dubose D, Rossi GD, Conrad BP, Horodyski M, et al. Total motion generated in the unstable thoracolumbar spine during management of the typical trauma patient: a comparison of methods in a cadaver model. J Neurosurg Spine. 2012;16:504–8.
10. Slocum HC, O'neal KC, Allen CR. Neurovascular complications from malposition on the operating table. Surg Gynecol Obstet. 1948;86:729–34.
11. Nandyala SV, Marquez-Lara A, Fineberg SJ, Singh R, Singh K. Incidence and risk factors for perioperative visual loss after spinal fusion. Spine J. 2014;14:1866–72.
12. Stevens WR, Glazer PA, Kelley SD, Lietman TM, Bradford DS. Ophthalmic complications after spinal surgery. Spine (Phila Pa 1976). 1997;22:1319–24.
13. Patil CG, Lad EM, Lad SP, Ho C, Boakye M. Visual loss after spine surgery: a population-based study. Spine (Phila Pa 1976). 2008;33:1491–6.
14. Lee LA, Roth S, Posner KL, Cheney FW, Caplan RA, Newman NJ, 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.
15. DePasse JM, Palumbo MA, Haque M, Eberson CP, Daniels AH. Complications associated with prone positioning in elective spinal surgery. World J Orthop. 2015;6(3):351–9.
16. Hayreh SS. Ischemic optic neuropathies—where are we now? Graefes Arch Clin Exp Ophthalmol. 2013;251:1873–84.
17. Stambough JL, Dolan D, Werner R, Godfrey E. Ophthalmologic complications associated with prone positioning in spine surgery. J Am Acad Orthop Surg. 2007;15:156–65.
18. Nickels TJ, Manlapaz MR, Farag E. Perioperative visual loss after spine surgery. World J Orthop. 2014;5:100–6.
19. Kamel IR, Drum ET, Koch SA, Whitten JA, Gaughan JP, Barnette RE, 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.
20. Chung I, Glow JA, Dimopoulos V, Walid MS, Smisson HF, Johnston KW, et al. Upper-limb somatosensory evoked potential monitoring in lumbosacral spine surgery: a prognostic marker for position-related ulnar nerve injury. Spine J. 2009;9:287–95.
21. Cho KT, Lee HJ. Prone position-related meralgia paresthetica after lumbar spinal surgery: a case report and review of the literature. J Korean Neurosurg Soc. 2008;44:392–5.
22. Burdet L, Liaudet L, Schaller MD, Broccard AF. Bilateral breast necrosis after prone position ventilation. Intensive Care Med. 2001;27:1435.
23. Koreckij J, Price N, Schwend RM. Vectored cranial-cervical traction limits facial contact pressure from prone positioning during posterior spinal deformity surgery. Spine. 2011;36(15):E993–7.

24. Grissel M. Face tissue pressure in prone positioning: a comparison of three face pillows while in the prone position for spinal surgery. Spine (Phila Pa 1976). 2008;33(26):2938–41.
25. Goodwin CR, Recinos PF, Omeis I, Momin EN, Witham TF, Bydon A, et al. Prevention of facial pressure ulcers using the Mayfield clamp for sacral tumor resection. J Neurosurg Spine. 2011;14:85–7.
26. Dahab R, Barrett C, Pillay R, De Matas M. Anterior thigh compartment syndrome after prone positioning for lumbosacral fixation. Eur Spine J. 2012;21:554.
27. Ahmad FU, Madhavan K, Trombly R, Levi AD. Anterior thigh compartment syndrome and local myonecrosis after posterior spine surgery on a Jackson table. World Neurosurg. 2012;78:553.e5–8.
28. Geisler FH, Laich DT, Goldflies M, Shepard A. Anterior tibial compartment syndrome as a positioning complication of the pronesitting position for lumbar surgery. Neurosurgery. 1993;33:1117.
29. Kwee MM, Ho YH, Rozen WM. The prone position during surgery and its complications: a systematic review and evidence-based guidelines. Int Surg. 2015;100:292–303.
30. Foster MR. Rhabdomyolysis in lumbar spine surgery: a case report. Spine (Phila Pa 1976). 2003; 28(14):E276–8.