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Brachial plexus injury following spinal surgery

A review

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Object. In the present study, the authors identified the etiology, precipitating factors, and outcomes of perioperative brachial plexus injuries following spine surgery.

Methods. We reviewed all the available literature regarding postoperative/perioperative brachial plexus injuries, with special concern for the patient's position during surgery, duration of surgery, the procedure performed, neurological outcome, and prognosis. We also reviewed the utility of intraoperative electrophysiological monitoring for prevention of these complications.

Results. Patient malpositioning during surgery is the main determining factor for the development of postoperative brachial plexus injury. Recovery occurs in the majority of cases but may require weeks to months of therapy after initial presentation.

Conclusion. Brachial plexus injuries are an increasingly recognized complication following spinal surgery. Proper attention to patient positioning with the use of intraoperative electrophysiological monitoring techniques could minimize injury. *(DOI: 10.3171/2010.4.SPINE09682)*

Key Words • **postoperative neuropathy** • **brachial plexus injury** • **positional brachial plexopathy** • **intraoperative electrophysiologic monitoring** • **somatosensory evoked potentials** • **motor evoked potentials**

Peripheral nerve injuries are among the most common perioperative complications, with brachial plexus injuries being the most significant. Brachial plexus injuries have been described for well over a century in the medical literature as occurring in patients who are malpositioned during surgery. These injuries have been reported to occur in patients in the supine position for heart surgery as well as in the prone position after prolonged spinal surgery. The number and complexity of spinal surgeries being performed has markedly grown, leading to an increase in the frequency of brachial plexus injuries.[29]

In this article we review the pertinent literature related to brachial plexus injury following spinal surgery. In addition, we discuss anatomy, etiology, risk factors, and recommendations to prevent such complications. We also review the utility of intraoperative electrophysiological monitoring for prevention of these complications.

Abbreviations used in this paper: EMG = electromyographic; MEP = motor evoked potential; SSEP = somatosensory evoked potential.

Anatomy and Pathophysiology of Brachial Plexus Injury

The brachial plexus lies between the neck and the axilla, with the distal portion lying behind the clavicle and the pectoral muscle. The brachial plexus is comprised of the C-5, C-6, C-7, C-8, and T-1 nerve roots and innervates all the muscles of the upper limb, with the exception of the trapezius and levator scapulae. The cutaneous innervation of the upper limb is supplied by the plexus with the exception of the region surrounding the axilla, the area just above the point of the shoulder, and the dorsal scapular region.

Injury to the brachial plexus is attributed to its long and superficial course in the axilla and its attachment to 2 firm points of fixation: the vertebrae proximally in the neck and the axillary fascia distally in the arm.[15] During its course, the brachial plexus passes in contact with 3 bony structures: the clavicle, which lies anteriorly; the first rib, which lies inferiorly; and the head of the humerus which lies posteriorly and laterally. This close proximity to freely moving bony structures makes these neural elements vulnerable to stretching and compression from malpositioning of the patient.

During general anesthesia, especially after the use of muscle relaxants, which reduce or abolish defensive muscle tone, the patient is at risk for injury. Brachial plexus injury can also result from nerve stretch or compression, with subsequent ischemia to the vasa nervorum.[44] Certain factors and comorbid conditions can predispose the patient to injury, such as hypovolemia and hypotension,[21] alcoholism,[16] diabetes mellitus,[25] and especially hypothermia.[1,17]

Methodology of Literature Search

The MEDLINE and OVID databases were used to conduct a literature search for articles in the English language that were published between 1950 and 2009 with the following key words and phrases: "(bilateral) brachial plexus injury," "postoperative brachial plexus injury," "brachial plexus injury in the prone position," "surgical malpositioning." Related articles were also searched for relevant titles. The MEDLINE database produced 7665 overlapping titles that were examined for relevance. The OVID database produced 6112 overlapping titles that were examined for relevance. Three reviewers chose the articles that appropriately fit the selection criteria. Only primary clinical articles discussing brachial plexus injuries were included. Duplicate titles were eliminated. We selected a total of 11 articles for review with attention to patient's positioning, type and duration of surgery, and final outcome. One of the articles discussed nonoperative brachial plexus injuries due to patients being maintained in a prone position and was included because of its relevance. We also reviewed the utility of intraoperative electrophysiological monitoring for prevention of these complications.

Results

A total of 17 patients out of the 517 identified in our literature search experienced postoperative brachial plexopathy after being in the prone position and another 44 after surgery in either the supine or lateral decubitus position. Brachial plexus injuries were most frequently described following cardiac surgery, althouth there has been a recent increase in the incidence following prone spinal surgery. We found that the neurological deficits reported varied from patient to patient with the majority of affected patients having both sensory and motor deficits. However, Ben-David and Stahl[5] described varied deficits according to patient position, with sensory deficits after cardiac surgery (supine) and motor deficits following noncardiac surgery (more often prone). The breakdown of motor and sensory deficits was not clearly mentioned in all the articles, so the distribution of deficits could not be inferred. The duration of surgery was only mentioned in 6 of the 11 articles and ranged from 3 to 11 hours. No clear correlation between duration of surgery and brachial plexus injury could be concluded.

When reviewing the position of the patients we found that the prone position with arms abducted greater than 90° was frequently associated with postoperative brachial plexus injuries. There were, however, other positions that led to stretch or compression of the brachial plexus and subsequent nerve injury. Extension and external rotation of the abducted arm, rotation and lateral flexion of the neck toward the same side (as this increases the tension on the brachial plexus on the opposite side), and the application of shoulder braces, especially if placed over the clavicle and not the acromion, have also been associated with brachial plexus injury.[18]

Prognosis and long-term recovery was very good in most cases. Improvement of symptoms occurred within weeks to months after initial presentation and following extensive rehabilitation. Some patients required longer periods of time for full recovery. However, only 5 patients out of the 61 presenting with brachial plexus injury suffered residual neurological deficit at 3 months.

We have compiled data from our review in 2 tables: Table 1 contains complications described in patients who were in the prone position,[22,42] while Table 2 presents brachial plexus injuries in patients lying supine or in other positions.[5,8,13,16,24,29,35,40,41]

Discussion

Peripheral nerve injuries occurring postoperatively due to patient malpositioning have been described in the literature for nearly a century, probably with a strong bias toward underreporting, and they still constitute a frequent

TABLE 1: Characteristics of cases involving brachial plexus injury related to the prone position

Authors & Year	No. of Cases	Pt Age in Yrs, Sex	Operation/Duration	Position	Injury	Recovery Time	Conclusion
Schwartz et al., 2000	15†	7–23	spinal surgery for scoliosis	prone	impending brachial plexopathies identified w/ SSEP recording	NA	positional brachial plexopathies can be avoided by intraoperative monitoring of SSEPs in patients undergoing surgery in the prone position
Goettler et al., 2002	2	34 & 52, 1 M & 1 F	prone for ARDS, or prone for necrotizing fasciitis of back	prone	both patients experienced symptoms suggestive of brachial plexus injury	2 weeks	brachial plexus injury is a complication in ICU patients after prone positioning (e.g., for ARDS treatment)

* ARDS = adult respiratory distress syndrome; ICU = intensive care unit; NA = not applicable; Pt = Patient.
† Out of a series of 500.

TABLE 2: Characteristics of cases in which patients presented with brachial plexus injury after surgery in nonprone positions*

Authors & Year	No. of Cases	Age (yrs), Sex	Operation & Duration	Position	Outcome	Recovery Time	Conclusion
Raffan, 1950	2	43 & 44; both F	hysterectomy	steep Trendelenburg w/ padded shoulder rest	generalized weakness and numbness of the right arm	1–4 mos	avoid abduction of arm in Trendelenburg position
Jackson & Keats, 1965	8	young adults	NS	“hands up” w/ arms abducted 90° & elbows flexed 90°, hands at level of ears, elbows at table level then raised 6” above table	marked stretching of the brachial plexus when the elbows were permitted to rest at the table level; 5 supine pts had no sequelae; 3 patients in different positions had sequelae		elevating the elbow 6” above the table level will prevent injury of brachial plexus in the “hands-up” position. limit arm abduction to 90° max, esp limit posterior displacement
Po & Hansen, 1969	5	13–43; 4 M & 1 F	2 ASD repairs; partial gastrectomy; thoracotomy; I&D of abscess; 3–11 hrs	rt ant lat w/ arms hyper-extended, supine w/ arms abducted > 90°	UE weakness & paresthesia	3 mos–2 yrs	arm board angle <90° to table; arms pronated; shoulder braces well padded and placed over acromium & not clavicles
Cooper et al., 1988	3	56–67; 2 M & 1 F	radical cystectomy; radical prostatectomy; shoulder arthroplasty; 5–6 hrs	2 cases of Trendelenburg w/ arms abducted 60°; Barber-chair position w/ arm abducted 90°	UE motor & sensory weakness	2 mos	several recommendations for prevention of brachial plexus injury
Ben-David & Stahl, 1997	22	52–60; 15 M & 7 F	8 OHS w/ median sternotomy, 14 NCS; NS		pts in OHS group, suffered sensory impairment & paresthesias; pts in NCS group suffered predominantly from motor dysfunction	10–20 wks; 1 of 8 in OHS group suffered residual neurol deficits; 3 of 14 in NCS group suffered persistent motor deficits	brachial plexus injury following cardiac surgery, predominantly characterized by sensory complaints, while injuries following noncardiac surgery were predominantly characterized by upper- & middle-root motor deficits
Chin & Poole, 2003	1	39 M	laparoscopic sigmoid colectomy, 3 hrs	low Lloyd-Davis position w/ both legs padded, both arms tucked into patient’s sides, supine at 20° Trendelenburg	bilat arm weakness & numbness, proximal motor & sensory deficits in both arms	6 mos	unexplained brachial plexus injury can occur despite careful positioning
Ngamprasertwong et al., 2004	1	42 M	laparoscopic radical nephrectomy, 7 hrs	rt lateral decubitus w/ lt arm hyperabducted to 120° & suspended from an L-shaped bar	numbness & weakness in lt UE	residual hyperthesia in affected limb 1 mo after discharge	in lat decubitus position always use a chest roll & avoid suspension of the arm from an L-shaped bar
Brunette et al., 2005	1	39 M	gastric bypass, 5 hrs	supine w/ arms on padded boards & abducted to 60° w/ 40° head up.	numbness & weakness in bilat arms & rt Horner syndrome.	9 mos	head-up position in obese pts w/o arm support is a risk factor for brachial plexus injury
Kent & Cheney, 2007	1	32 M	laparascopic sigmoid colectomy, 3 hrs	supine w/ 20° head down & arms abducted to 60°, shoulder braces placed to prevent sliding	bilat weakness & numbness in UEs	3.5 yrs w/o full recovery	neurovascular compression manifested by difficulty in obtaining BP can be a consequence of shoulder brace placement & lead to brachial plexus injury

* I&D = irrigation and debridement; neurol = neurological; NCS = noncardiac surgery; NS = not specified; OHS = open-heart surgery; UE = upper extremity.

cause for malpractice claims. Initially, there were 2 theories of possible causes of nerve injury. The first theory was that nerve injuries were due to the toxic effects of the anesthetic agents. The second theory was described by Budinger in 1894; he correctly postulated that it is the patient's malpositioning on the operating table that is the principal cause of nerve injury.[9] Of all the peripheral nerve groups, the brachial plexus is the most frequently injured by malpositioning.[7]

Peripheral nerve injuries can occur in 3 basic ways: stretching, compression, or laceration. In the perioperative setting, laceration to the nerve is the least likely to occur with compression and stretching being the most likely. Table 3 illustrates the Seddon classification,[27] which correlates the exact degree of nerve injury with pathology, prognosis, and symptomatology. Typically, 3 main types of nerve injuries are described in the neurological literature: neurotemesis, axonotemesis, and neuropraxia. Postoperative brachial plexus injuries are usually either neuropraxia or axonotemesis.

Neurological injuries due to improper positioning occur in 0.14% of surgical cases, of which brachial plexus injuries[38] represent 38%. Due to its long and superficial course in the axilla, the brachial plexus is easily susceptible to damage from malpositioning. Brachial plexus injuries occur most frequently when the patient is in the prone position and especially when the arms are abducted to more than 90°. In this position, traction of the brachial plexus and compression between the clavicle and first rib is responsible for the neurological deficit. Patients in the lateral decubitus position are prone to brachial plexus injury from compression when the dependent arm and shoulder are positioned between the thorax and the table. This can be prevented by positioning the dependent shoulder and arm anterior to the thorax.[29]

Recovery is the rule in most cases after an adequate follow-up period with no permanent deficits being reported.[30] The prognosis is good; however, duration of recovery can vary from hours to months. Jackson and Keats[24] described the pattern of return of function, with sensation returning first in most of the cases followed by motor function of the lower roots and motor function of the upper root returning last. Brachial plexus injury following cardiac surgery usually results in sensory deficits, while injuries following noncardiac surgeries usually result in motor deficits.

Electrophysiological Intraoperative Monitoring

Intraoperative electrophysiological monitoring techniques, (such as SSEP, MEP, and EMG monitoring), in patients undergoing spine surgery in the prone position may be helpful for early detection of neurological deficits. Somatosensory evoked potentials constitute an evoked response generated from nerve tracts and nuclei in the brain or cortical surface electrodes after stimulation of the peripheral nerves.[14] Monitoring of SSEPs has gained universal acceptance in its use for intraoperative monitoring of spinal cord function, but its use and effectiveness as a warning against peripheral nerve injury is still debatable. Monitoring of SSEPs is a valuable tool for the detection of neural and vascular compromise of the brain and nerves. It involves the electrical stimulation of peripheral nerves followed by the recording of electrical potentials from the scalp and is indicated as the mainstay of spinal surgery. Monitoring of MEPs involves transcranial electrical stimulation of the motor cortex with cutaneous scalp electrodes that record contralateral muscle contractions. Electromyography assesses nerve roots "or peripheral nerves" that are correlated to myotomes "or muscle" by recording muscle activity during surgical procedures while stimulating individual segmental nerve roots "or peripheral nerves."

Somatosensory Evoked Potentials

Currently, there are multiple reports about the validity of SSEPs in the detection of peripheral nerve injury. Multiple criteria suggest that deviations in amplitude or latency are both reliable measures for detecting nerve injury. The most used threshold values for amplitude and latency in the detection of nerve injury from 4 published studies are summarized in Table 4.[3,31,37,42]

Multiple published reports have accepted a threshold range (with Schwartz et al.[42] reporting the most conservative values) for amplitude and latency that may correlate with and be representative of peripheral nerve injury. These changes in amplitude and/or latency may be important in identifying patient malpositioning and ultimately avoiding postoperative neurological deficits. However, authors have debated the validity of SSEP monitoring as predictors of postoperative nerve injuries. In 2 studies with criteria of an amplitude decrease of 60% or more and/or a latency increase of 10% or more, Pelosi et al.[39] and Lorenzini and Poterack[32] concluded that SSEPs had a false-negative rate of 37.5%–42.8% and therefore are not a good prognostic marker for the detection of position-related nerve injuries.[32,39]

TABLE 3: Classification of neural injury type with associated characteristics*

Injury Type	Etiology	Clinical Presentation	Pathology	Recovery
neuropraxia	compression or ischemia	motor deficits > sensory deficits, autonomic function preserved	axonal continuity preserved	complete
axonotmesis	crush or stretch	motor, sensory, & autonomic deficits	damage to axons w/ preservation of neural connective tissue	complete
neurotmesis	severe contusion, stretch, or laceration	complete loss of motor, sensory, & autonomic function	axon, myelin, & connective tissue damaged, disrupted, or transected	incomplete

* Summary of the Seddon classification.[27]

A retrospective study of 1000 patients undergoing spine surgery was performed to demonstrate the use of SSEP to determine the relationship between patient positioning and impending upper-extremity nerve injury.[26] Seventy-four patients (7.4%) demonstrated SSEP changes, 68 of which were position related, and the SSEP changes were reversed by modifying the arm position. This study emphasized the value of SSEP monitoring in identifying and reversing impending upper-extremity peripheral nerve injury. Additionally, in a multicenter survey study that included 51,263 spinal surgery cases, SSEP monitoring produced a false-negative rate of 0.063% and a false-positive rate of 0.983%. This supports the clinical efficacy of SSEPs in the prediction of postoperative neurological deficits.[36]

Another retrospective study was performed involving 432 pediatric patients who underwent surgical correction of scoliosis while being assessed for positional brachial plexopathy through monitoring of the ulnar nerve SSEPs.[31] The results of the study showed that 27 patients (6.2%) had an ulnar nerve amplitude decrease of more than 30% while in the prone position, accounting for a higher rate of brachial plexopathy. The study concluded that avoidance of brachial plexus injury during scoliosis surgery is possible by early detection of ulnar nerve SSEP monitoring.

Motor Evoked Potentials

In recent years, MEPs have also been recorded as another monitoring modality used during spine surgery. Motor evoked potentials were originally introduced in monitoring the anterior regions of the spinal cord. Their role in detecting peripheral nerve injuries has not been established, however, and warrants further prospective studies. The positive predictive value, as shown by Chen et al.[12] in 341 patients undergoing high-risk neurosurgical or orthopedic procedures, reaches 94.8% in the upper extremity but only 66.6% for the lower extremity,[20] when used in the detection of motor deficits in the postoperative patient. However, MEPs have certain limitations when used for patients under 6 years of age and patients with preexisting neurological diseases such as spinal cord compression and diabetic neuropathy.[20,43] Despite the proven safety of MEP monitoring, there are relative contraindications that preclude its use, including epilepsy, cortical lesions, raised intracranial pressure, cardiac disease, and the presence of pacemakers.[33] Despite these limitations, 2 robust studies have demonstrated high sensitivity and specificity of this modality in predicting motor deficits in spine surgery.[10,11]

Electromyography has been added to SSEP and MEP monitoring as part of multimodal monitoring in spinal surgery, due to the absence of a single reliable technique in the detection of nerve injury. Electromyographic monitoring alone has proven to be an effective technique in the detection of local nerve root injury in 2 studies by Bose et al.[6] and Maguire et al.[34] Both studies demonstrated that using EMG monitoring resulted in a sensitivity of 93% in the detection of nerve injury; however, another study performed by Beatty et al.[4] has shown a false-negative rate of 20%–23%. Electromyography is a valuable and inexpensive technique that can provide spine surgeons with real-time monitoring and feedback, but like other monitoring modalities its results are inconsistent and it is not adequate for use on its own (that is, without other modalities).

TABLE 4: Amplitude and latency threshold values associated with minimal or no residual injury

Amplitude		Latency	Reference
decrease of ≥ 50%	&/or	increase of ≥ 20%	Balzer et al., 1998
decrease of ≥ 60%	&/or	increase of ≥ 10%	O'Brien et al., 1994
decrease of ≥ 30%	&/or	increase of ≥ 10%	Labrom et al., 2005; Schwartz et al., 2000

It has been proposed that the combination of SSEP with MEP monitoring reduces false-positive results and has a greater sensitivity than SSEP alone.[23] A prospective study of 246 patients undergoing cervical spine surgery performed between March 2000 and December 2005 using intraoperative multimodality monitoring (SSEP, MEP, and EMG) demonstrated a sensitivity of 83.3% and a specificity of 99.2%.[19] Another study performed by Kelleher et al.[28] showed that multimodality monitoring with SSEP, MEP, and EMG was helpful in detection and prevention of neurological deficits during cervical spine surgery, as opposed to single-modality monitoring alone.

Recommendations

Based on the Level III evidence available, we offer the following Grade B recommendations regarding prevention of brachial plexus injuries. Prevention of brachial plexus injury in patients undergoing surgery entails careful positioning and padding of the arms, chest, and neck. When patients are in the prone position abduction should be limited to less than 90° to reduce the risk of injury. In cases in which 90° of abduction is necessary, the elbow should not be fully extended (instead, it is better for the elbow to be bent at 90°, allowing the hand to lie alongside the head).[2] Extension and external rotation of the abducted arm must be avoided as this increases the stretch on the brachial plexus. Rotation and lateral flexion of the neck toward the same side should be avoided as this increases the tension on the brachial plexus on the opposite side.[2]

Recent surgical advances permit access to spinal structures with patients in the lateral position. In the event that surgery is performed with the patient in the lateral decubitus position, his or her dependent arm should be placed anterior to the thorax to avoid compression of the brachial plexus between the thorax and the operating table. Patients in the lateral decubitus position should not have their arm suspended from an L-shaped bar. A soft cervical collar may help prevent postoperative nerve injury by keeping the head and cervical spine in a neutral position.

If the patient is supine with hands up, the elbow should be elevated at least 6 inches above the table level to prevent stretching of the brachial plexus. Frequent re-positioning of the patient's arms during the procedure is important when feasible if the position is suspected to cause stretch and compression of the brachial plexus.

Surgeons might also consider using transparent drapes so that the surgical and anesthesiology staff may have a constant view of the patient's position during surgery and the SSEP monitoring period.

Shoulder braces have long been used to prevent patient movement on the operating table; however, there use has been associated with an increased incidence of brachial plexus injury. Therefore, we recommend restricting use of shoulder braces whenever possible.

No single predictive monitoring modality has been shown to be superior; the use of multimodality testing (SSEP and MEP) for intraoperative monitoring is best for early identification and reversing impending upper-extremity peripheral nerve injury, in addition to the original role of monitoring spinal cord function.

Conclusions

Brachial plexus injuries are an increasingly recognized complication following spinal surgery. Recovery is the rule in most cases. Proper attention to patient positioning with the use of intraoperative electrophysiological monitoring techniques could potentially minimize injury.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Uribe, Camporesi. Acquisition of data: Kolla, Omar, Dakwar. Analysis and interpretation of data: Camporesi. Drafting the article: Kolla, Omar, Dakwar, Camporesi. Critically revising the article: Uribe, Dakwar, Abel. Reviewed final version of the manuscript and approved it for submission: all authors. Administrative/technical/material support: Mangar. Study supervision: Uribe, Mangar, Camporesi.

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