A patient presented for elective shoulder arthroscopy who had subclavian steal syndrome. The patient’s history included bilateral mastectomy with unilateral lymph node dissection, limiting noninvasive oscillometric blood pressure monitoring on the nonoperative side. This history, combined with the necessary surgical positioning and calf blood pressure monitoring, raised the concern of decreased cerebral perfusion during a general anesthetic in the beach chair position. This report describes the management of this particular case, then reviews the relevant literature regarding cardiovascular and cerebral perfusion monitoring.

**Keywords:** Axillary lymph node dissection, noninvasive cardiovascular monitoring, shoulder arthroscopy sitting position, subclavian steal syndrome.

This case report aims to review, discuss, and perform a post-hoc analysis of the management of a patient presenting for elective shoulder arthroscopy who had subclavian steal syndrome (SSS). Each year approximately 1.4 million shoulder arthroscopies are performed worldwide. Many of these are performed in the beach chair position, a position that when combined with general anesthesia reduces cerebral perfusion pressure (Table 1). Beach chair position was first introduced in the 1980s as an alternative to lateral decubitus position for shoulder surgery and is favored because of its reduction in brachial plexus injury and anatomical optimization.

The major anesthetic concern related to SSS is its potential effect on the cerebral circulation. This syndrome is defined as flow reversal in the vertebral artery on the same side as a proximally obstructed subclavian artery (Figure 1). The lesion in the proximal subclavian artery reduces aortic blood flow through the subclavian artery and allows retrograde flow from the circle of Willis to return down the basilar artery, into the vertebral artery, which then backfills the subclavian artery distal to the obstruction. This flow reversal steals cerebral circulation and perfuses the extremity.

To further complicate matters in this case, the oscillometric blood pressure cuff had to be placed on the patient’s calf to avoid the axillary lymph node–dissected arm in accordance with hospital policy. This policy is designed to reduce the risk of lymphedema. Lymphedema develops when the lymphatic system is unable to remove accumulated interstitial fluid, and it affects up to 5 million Americans. Among breast cancer survivors, the occurrence of lymphedema varies widely. Regardless, many institutions maintain policies that restrict needle sticks and blood pressure cuffs on axillary lymph node–dissected extremities.

**Case Summary**
A 65-year-old woman presented for right shoulder ar-

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**Table 1.** Noninvasive Blood Pressure (NIBP) Sites and Gradient in Sitting Position

<table>
<thead>
<tr>
<th>NIBP cuff placement</th>
<th>Distance from circle of Willis, cm</th>
<th>Gradient, mm Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brachial (upper arm)</td>
<td>10-30</td>
<td>8-24</td>
</tr>
<tr>
<td>Radial (lower arm)</td>
<td>35-50</td>
<td>27-39</td>
</tr>
<tr>
<td>Tibial (calf)</td>
<td>60-80</td>
<td>46-62</td>
</tr>
</tbody>
</table>

Abbreviations: L, left; R, right.

**Figure 1.** Subclavian Steal Syndrome (SSS)
Defined as flow reversal in vertebral artery on ipsilateral side of obstructive lesion in subclavian artery, SSS is demonstrated in left subclavian artery.
throscopy with possible open rotator cuff repair. Her medical history was remarkable for asthma, fibromyalgia, gastroesophageal reflux disease (GERD), Mobitz type 1 atrioventricular block, hypertension, supraventricular tachycardia, irritable bowel syndrome, systemic lupus erythematosus, breast cancer treated with bilateral mastectomy with left-sided axillary lymph node dissection, and SSS of unknown laterality. Her medication list included hydrochlorothiazide, melatonin, multivitamin, lansoprazole, pantoprazole, ranitidine, simvastatin, vitamin B12, cetirizine, and albuterol. Results of preoperative laboratory and cardiac studies were within normal limits. Her ASA physical status was assigned as 2, although 3 previous anesthetic evaluations assigned a physical status of 3.

Her baseline vital signs were as follows: heart rate of 81/min, respiratory rate of 22/min, and blood pressure of 126/84 mm Hg. She was 1.57 m tall and weighed 66 kg, with a body mass index of 26.7 kg/m². The patient was allergic to penicillin and sulfa drugs. She reported a history of aspiration during a sedated colonoscopy secondary to her hiatal hernia and poorly controlled GERD, but no other anesthesia-related complications. She reported activity that required greater than 4 metabolic equivalents without dyspnea or angina. Unfortunately, she was not routinely followed up at the institution at which she presented for surgery; consequently, no additional information regarding her SSS laterality, severity, or treatment was available.

Hospital policy prevented the preoperative registered nurse from obtaining bilateral upper extremity blood pressures because of her history of axillary lymph node dissection. However, she did not report any vertebrobasilar symptoms or arm claudication, and it was presumed that she was medically managed based on her medication list. These conclusions pacified some of the major concerns of the anesthesia team.

The routine anesthetic for shoulder arthroscopy at the institution is a general anesthetic with an interscalene block. The nonoperative extremity is used for noninvasive oscillometric blood pressure monitoring and peripheral intravenous (PIV) catheter placement. The patients are placed in the beach chair position after anesthetic induction and airway management.

Preoperatively, because of the patient's left axillary lymph node dissection and right-sided shoulder surgery, a left external jugular PIV catheter was placed and an oscillometric blood pressure cuff was placed on the calf. An interscalene block was placed in the right shoulder with mild midazolam and fentanyl sedation. The use of a percutaneously placed radial arterial catheter was ruled out secondary to hospital policy regarding axillary lymph node dissections and needle sticks. Instead, the calf cuff pressure was to be used with compensation made for the hydrostatic gradient. The blood pressure gradient, between the calf and tragus, was estimated to be 45 mm Hg based on an approximate 60-cm height difference (see Table 1). Noninvasive continuous cardiac output and arterial pressure monitoring was achieved using the ClearSight System (Edwards Lifesciences Corp). The finger cuff was placed on the left third digit with the fingerside heart reference sensor attached; the heart-side heart reference sensor was clipped at the level of the heart per the manufacturer's instruction (Figure 2).

It is recommended to maintain the patient's blood pressure within 20% of baseline throughout an anesthetic to ensure adequate end-organ perfusion. With the preoperative blood pressure of 126/84 mm Hg and a calculated mean arterial pressure (MAP) of 98 mm Hg noted, the intraoperative goal was to maintain a MAP of at least 78 mm Hg at the circle of Willis; this would require a calf MAP of 123 mm Hg: (123[Calf] – 45[Gradient] = 78), as shown in Table 1.

The patient was brought into the operating room, and
monitors were applied. Anesthesia was induced intravenously, the trachea was intubated, and the lungs were mechanically ventilated with a tidal volume of 500 mL, respiratory rate of 12/min, positive end-expiratory pressure of 5 cm H₂O, and inspired oxygen concentration of 60%. Anesthesia was maintained with inhaled 0.9% sevoflurane in an air and oxygen mixture.

Immediately after beach chair positioning and just before the incision was made, the patient experienced moments of hypotension, with calf MAPs of 80 mm Hg or lower. A phenylephrine infusion was initiated and rapidly titrated to 200 μg/min with ephedrine, norepinephrine, and vasopressin boluses while the anesthetic concentration was simultaneously reduced. The calf MAP remained between 90 and 95 mm Hg throughout the procedure despite the pharmacologic support. All other vital signs were within normal limits throughout the case. The heart rate ranged from 70 to 85/min in normal sinus rhythm, end-tidal carbon dioxide was 31 to 45 mm Hg, skin temperature ranged from 35.7° to 36.1°C, and pulse oximetry readings were between 96% and 100%.

The ClearSight System measured the MAP 10 to 20 mm Hg lower than the calf oscillometric pressure and provided an estimated stroke volume of 47 to 53 mL and a cardiac index of approximately 2.7 L/min/m² throughout the procedure. Because the SSS laterality was unknown, it was difficult to trust the data provided by the ClearSight System; however, an oscillometric cuff on that extremity would have been just as vulnerable to any such vasculopathy. Regardless, the preoperative plan consisted of clinical responses to the calf oscillometric blood pressure with an adjustment made for the hydrostatic gradient.

Toward the conclusion of the case the patient was allowed to spontaneously ventilate as the anesthetic was reduced during dressing and sling placement. The phenylephrine infusion was simultaneously reduced as the anesthetic was decreased, and the oscillometric calf MAP increased to between 95 to 110 mm Hg. After the patient met the established extubation criteria, her trachea was extubated as she remained in the beach chair position.

She was transferred to a stretcher and escorted to the postanesthesia care unit (PACU) for recovery with supplemental oxygen via face mask at 6 L/min. In the PACU a neurologic examination was performed, and the patient was found to be alert and oriented to person, place, and year. She was able to move 3 of her extremities to command, and cranial nerves II through X and cranial nerve XII were intact. The spinal accessory (cranial nerve XI) and right arm were unable to be adequately assessed because of the unilateral interscalene block. No negative sequelae developed related to her anesthetic or hemodynamic management. She was discharged later that same day.

Discussion

• Beach Chair Position. A priority consideration in patients presenting for elective shoulder surgery is related to their positioning. Blood behaves as fluid in a column; when a patient is in the upright position a blood pressure gradient between the circle of Willis and heart is created (see Table 1). It is often recommended to place an arterial line and level the transducer at the patient’s tragus to estimate the blood pressure in the circle of Willis when there are major concerns related to cerebral perfusion. Because of this patient’s lack of vertebrobasilar symptoms, conservative medical management, and history of axillary lymph node dissection, an arterial line was believed to be excessive.

Most publications recommend maintaining blood pressure within 20% of the patient’s preoperative baseline when in a sitting or beach chair position. However, there is no established “minimally safe” blood pressure in the sitting or beach chair position, and it is presumed to be patient dependent. Awake patients placed in the beach chair or sitting position demonstrated unchanged or slightly increased blood pressures. However, the vasodilatory effects of general anesthesia, coupled with blood pooling in the lower extremities, can cause sudden and severe hypotension after positioning, much like this patient experienced.

Four case reports have been published in which irreversible neurologic damage was described due to global cerebral hypoperfusion secondary to the sitting position and hypotension. The consequences are substantial; therefore, when one places a patient into the sitting or beach chair position, careful anesthetic, vasopressor, and positioning titration is mandatory to prevent sudden, potentially catastrophic, hypotension. The use of the lateral decubitus position to eliminate hydrostatic gradients could have been considered in this case. However, this decision must include both anesthetic and surgical teams and may have been difficult to negotiate.

• Subclavian Steal Syndrome. Subclavian steal syndrome was first described in the 1960s and has a reported incidence of 0.6% to 6.4%. Of individuals with SSS, approximately 5.3% have neurologic symptoms. These include vertebrobasilar symptoms such as vertigo, dizziness, ataxia, and syncope indicating cerebral hypoperfusion. Additional symptoms that should alert the practitioner to SSS include arm ischemia presenting as claudication, paresthesias, or weakness; however, these symptoms are difficult to assess and elicit because of the collateral circulation provided by the cerebral circulation.

Preoperative evaluation of patients with SSS can include comparison of upper extremity blood pressures. A gradient between extremities of greater than 15 to 20 mm Hg has been shown to be a sensitive indicator of subclavian steal; a gradient of 40 mm Hg or greater can be predictive of a partial or complete SSS. However, computed tomography or magnetic resonance angiography remain the gold standards for diagnosis. For most
patients, medical management of comorbidities such as diabetes mellitus, hyperlipidemia, and hypertension may be all that is necessary. For the 1.4% of severe refractory cases, surgical options such as carotid-subclavian bypass grafting or endovascular treatments are available.\(^3,11\)

Despite the low incidence of severe complications of SSS, several studies described patients who experienced more alarming signs of SSS indicative of brainstem ischemia.\(^12-14\) The severity of these symptoms has been questioned when controlling for anterior cerebral circulation disease\(^15\); however, patients with a diagnosis of SSS can be presumed to have systemic atherosclerotic changes, and anesthesia should be diligently managed.

- **Blood Pressure Measurement and Interpretation.**

  Most patients undergoing surgery will have their blood pressure measured via the oscillometric technique. Briefly, this technique employs an appropriately sized cuff placed circumferentially around a patient's extremity. The cuff's bladder is inflated with air to a preset value and slowly released. As the cuff pressure is released, oscillations are detected and the peak amplitude is recorded as the MAP.\(^16\) Unfortunately, the systolic and diastolic pressures are determined by manufacturers' proprietary algorithms, unavailable for public review.\(^16\)

  There are times when an oscillometric-derived blood pressure measurement is inaccurate. For example, cuff placement is an important consideration; a study performed in women undergoing cesarean delivery demonstrated markedly variable oscillometric blood pressure values measured at the patient's ankle and those obtained from the upper arm.\(^17\) Atrial fibrillation has also been demonstrated to affect the accuracy of the oscillometric blood pressures\(^18,19\) and oscillometric cuffs tend to underestimate blood pressure compared with manual auscultatory methods.\(^20,21\) In light of these limitations, the prudent practitioner should remain skeptical when the obtained blood pressure is incongruent with the clinical scenario.

  In contrast, the ClearSight System is a noninvasive form of continuous arterial blood pressure and cardiac output monitoring.\(^22\) The underlying science was developed in the 1970s by Penaz\(^23\) but has recently gained popularity. It is completely noninvasive and uses a finger cuff placed on the intermediate phalange (Figure 3). The basis of this technology is the volume clamp method, also known as vascular unloading.\(^16,22\) The cuff is inflated and adjusted upwards of 1,000 times per second\(^7\) to maintain a constant arterial vessel volume by providing equal pressure on the arterial walls, and the volume is assessed continuously by built-in photoplethysmography (Figure 4).\(^22,24\)

  Studies have been performed to determine the accuracy of this device. Teboul et al\(^24\) concluded that “validation studies showed good agreement and trending ability in the perioperative context”, but these results were not as promising in patients with major changes in vascular tone. Similarly, another study concluded that in cases of severe vasoconstriction or peripheral vascular disease, it may be difficult to obtain reliable signals.\(^16\) A 2014 study demonstrated a bias (SD) of 3.5 (6.8) mm Hg between oscillometric and ClearSight System technologies.\(^25\)

  Practically, this means that a MAP of 60 mm Hg correlates to an oscillometric blood pressure cuff measurement of between 50.1 and 66.9 mm Hg with 95% certainty.\(^26\) It is known that even short periods of hypotension can adversely affect end-organ function.\(^27,28\) Results of a recent randomized controlled trial demonstrated significantly shorter periods of hypotension in beach chair-positioned patients when continuous blood pres-
sure monitoring modalities were used compared with intermittent blood pressure modalities. More generally, it has been suggested that the use of a continuous noninvasive blood pressure monitor can reduce the time spent in hypotensive states by 14 (3) min/h. This is precisely the value of this additional monitor: by allowing continuous arterial blood pressure monitoring, the patient did not experience prolonged periods of hypotension before interventions could be initiated. A practical method of stepwise escalation of blood pressure modalities is suggested by Meidert and Saugel (Figure 5).

- **Near-Infrared Spectroscopy (NIRS)**. Institutions that have NIRS cerebral oximeters may consider using them in patients undergoing procedures with a high risk of cerebral hypoperfusion and emboli, such as cardiac surgery. This technology uses an adhesive pad placed on the patient’s forehead that emits near-infrared light. This light is attenuated by chromophores, specifically, oxygenated hemoglobin, and thus can calculate the amount of saturated hemoglobin in the cerebral arteries and veins based on the degree of attenuation.

A 2012 prospective observational study demonstrated a significant correlation between the cerebral oximetry values and MAP of the cerebrum. Additionally, a 2010 prospective study demonstrated significant cerebral desaturation events, defined as 20% or more reduction in baseline NIRS value, in patients placed in the beach chair position compared with the lateral decubitus position. These desaturations did not occur in the laterally positioned patients, despite the lack of significant hemodynamic differences between the groups. From these study findings, a practitioner could conclude that, in lieu of an arterial line or an oscillometric blood pressure cuff on the upper extremity, a noninvasive cerebral oximeter could be used to determine adequate cerebral perfusion.

However, results of another study, performed in patients undergoing shoulder surgery with regional anesthesia and sedation, demonstrated that 99% of the group experienced hypotension, but only 10% experienced cerebral desaturation. The authors concluded that the presence of cerebrovascular disease was associated with the cerebral desaturation. Taken together, a NIRS cerebral oximeter would have been an excellent adjunct to the author’s noninvasive arsenal by providing real-time cerebral perfusion data in a vasculopathic patient in the beach chair position.

- **Peripheral Intravenous Catheters and High-Dose Vasopressors**. The use of high-dose vasopressors administered through a PIV catheter during this case, both infusions and boluses, demand brief consideration. In the emergency and intensive care departments it has been traditionally taught that a central venous catheter is required for patients receiving vasoactive infusions. This fear stems from extravasation case studies published during the 1950s and 1960s. However, little, if any, robust evidence supports this notion. Authors of several recent studies have concluded that the PIV extravasation rate is 2% to 14% with vasoactive infusions. Factors determined to increase the risk of extravasation included duration of the infusion and the site; sites distal to the antecubital or popliteal fossa and infusions lasting greater than 24 hours increased the risk. Central venous catheters, with their associated morbidity (> 15%), appear to be unnecessary when a larger-caliber vessel is cannulated for short infusions.

- **Lymph Node Dissection**. The added complexity of a lymph node dissection also necessitates a brief discussion. It is recommended by most oncologic associations to avoid needle sticks or blood pressure measurements in the affected limb. Unfortunately, most of these recommendations are based on low levels of evidence, including individual case reports, some of which date to the early 1920s. However, these recommendations include the option to place a PIV or arterial line in the affected extremity in patients with difficult intravenous access or surgical site limitations. One case study described a patient in whom lymphedema developed 30 years after mastectomy because of a recent diagnosis of diabetes mellitus and daily finger sticks for glucose management; therefore, the risk related to needle sticks should not be entirely disregarded.

The risk of using a blood pressure cuff on the lymph node–dissected extremity is unclear because of the
paucity of available data. Placing a blood pressure cuff on the affected extremity may be reasonable when you consider that one of the principle treatments of lymphedema includes compression stockings, which often generate and maintain pressures well above those of a blood pressure cuff. Additionally, a case series explored the role of tourniquets in patients undergoing elective hand surgery who had a history of axillary lymph node dissection, and the authors found there was no increase in the incidence of lymphedema. It is unclear where this dogma first began, and there is a lack of data to support it. The use of the lymph node–dissected arm for oscillometric blood pressure measurement can be considered an appropriate clinical decision dependent on the patient and the proposed surgical intervention.

Conclusion

The objective of this article was to review a unique case and share the post-hoc analysis. The preoperative evaluation of these patients can include bilateral upper extremity blood pressure measurement to assess the severity of SSS, as well as a detailed history regarding arm ischemia or vertebrobasilar symptoms. An arterial line with the transducer leveled at the tragus, despite the associated risk of infection and lymphedema, may be warranted in severe cases of SSS (Table 2). Additionally, placement of an oscillometric blood pressure cuff on the lymph node–dissected extremity should be considered in view of the benefits, risks, and recommendations. Based on this literature review, it appears that sole reliance on oscillometric blood pressures obtained on a patient’s calf would put a patient such as this at unnecessary risk.

Furthermore, after a review of the literature, it appears that the Edwards Lifesciences ClearSight System is capable of providing reliable and accurate arterial blood pressure measurements. Because it was unknown which extremity was affected by SSS in the patient described, the gradient between the oscillometric blood pressure and the ClearSight cuff may have been reflective of left arm vascular obstruction, a limitation specified by the manufacturer. Due to the complexity of this particular case, the use of both modalities was synergistic: allowing for continuous noninvasive arterial blood pressure monitoring and verification on an unobstructed extremity (the leg).

Managing similar cases using continuous noninvasive arterial blood pressure monitoring and oscillometric cuffs, with or without NIRs technology, may help guide therapy by triangulating adequate perfusion pressures. The practitioner must be well versed in all forms of cardiovascular monitoring techniques, their alternatives, and their limitations to maintain vigilance for such complex cases.

Table 2. Diagnosis, Signs, and Symptoms of Subclavian Steal Syndrome

<table>
<thead>
<tr>
<th>Signs</th>
<th>Symptom</th>
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<tr>
<td>&gt; 15 mm Hg discrepancy in upper extremities</td>
<td>Arm claudication</td>
</tr>
<tr>
<td>Delayed or decreased amplitude pulses in affected side</td>
<td>Subclavicular bruit</td>
</tr>
<tr>
<td>Subclavian steal</td>
<td>Coronal ischemia with internal mammary arterial graft has been used</td>
</tr>
<tr>
<td>Atrophic changes to skin/nails on affected side</td>
<td>Magnetic resonance angiography</td>
</tr>
<tr>
<td>Arm paresthesias</td>
<td>Computed tomography angiography</td>
</tr>
<tr>
<td>Cool arm</td>
<td>Continuous wave Doppler and duplex ultrasonography</td>
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REFERENCES


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