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Effect of ventilation on cerebral oxygenation in patients undergoing surgery in the beach chair position: a randomized controlled trial

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Editor's key points

- Anaesthesia in the beach chair position commonly causes systemic hypotension.
- It may also reduce cerebral blood flow (CBF) and oxygenation.
- Hypocarbia reduces CBF and oxygen delivery.
- The authors report fewer cerebral desaturation events when ventilation is adjusted to achieve E'_{CO_2} of 40–42 when compared with 30–32 mm Hg.

Background. Surgery in the beach chair position (BCP) may reduce cerebral blood flow and oxygenation, resulting in neurological injuries. The authors tested the hypothesis that a ventilation strategy designed to achieve end-tidal carbon dioxide (E'_{CO_2}) values of 40–42 mm Hg would increase cerebral oxygenation (Sct_{O_2}) during BCP shoulder surgery compared with a ventilation strategy designed to achieve E'_{CO_2} values of 30–32 mm Hg.

Methods. Seventy patients undergoing shoulder surgery in the BCP with general anaesthesia were enrolled in this randomized controlled trial. Mechanical ventilation was adjusted to maintain an E'_{CO_2} of 30–32 mm Hg in the control group and an E'_{CO_2} of 40–42 mm Hg in the study group. Cerebral oxygenation was monitored continuously in the operating theatre using near-infrared spectroscopy. Baseline haemodynamics and Sct_{O_2} were obtained before induction of anaesthesia, and these values were then measured and recorded continuously from induction of anaesthesia until tracheal extubation. The number of cerebral desaturation events (CDEs) (defined as a ≥20% reduction in Sct_{O_2} from baseline values) was recorded.

Results. No significant differences between the groups were observed in haemodynamic variables or phenylephrine interventions during the surgical procedure. Sct_{O_2} values were significantly higher in the study 40–42 group throughout the intraoperative period ($P<0.01$). In addition, the incidence of CDEs was lower in the study 40–42 group (8.8%) compared with the control 30–32 group (55.6%, $P<0.0001$).

Conclusions. Cerebral oxygenation is significantly improved during BCP surgery when ventilation is adjusted to maintain E'_{CO_2} at 40–42 mm Hg compared with 30–32 mm Hg.

Clinical trial registration. ClinicalTrials.gov NCT01546636.

Keywords: patient positioning; spectroscopy, near-infrared; ventilation

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Approximately 70% of shoulder surgical procedures in the USA are conducted in the beach chair position (BCP), which permits improved intraarticular visualization compared with the lateral decubitus approach.[1] Recent case reports, however, have raised concerns that the BCP may be a risk factor for the development of central nervous system ischaemic injury.[2–6] Although the aetiology of these adverse events was not established, most authors hypothesized that reductions in cerebral blood flow (CBF) resulted in cerebral and spinal cord ischaemia and infarction. Several factors may contribute to reductions in CBF during BCP shoulder surgery, which include patient positioning (hypotension in the sitting position),[2 7] use of anaesthetic agents (venous pooling in the lower extremities, reductions in cardiac output),[8] flexion or extension of the head (mechanical obstruction of arterial or venous vessels), or mechanical ventilation (hyperventilation and positive pressure ventilation).[9 10]

Near-infrared spectroscopy (NIRS) is a non-invasive technology that allows real-time assessment of the adequacy of cerebral tissue oxygenation (and, indirectly, of CBF) in the operating theatre setting. The technique is based on the transmission and absorption of near-infrared light as it passes through tissue (frontal cortex). Oxygenated and deoxygenated haemoglobin have different absorption spectra, and regional oxygen saturation in cerebral tissue can be determined by measuring the differential absorption of light as it passes through a curvilinear path from the light sources to the detectors. Studies have demonstrated that Sct_{O_2} measured with NIRS is concordant with CBF variations when arterial oxygen saturation and cerebral oxygen consumption are constant.[11] Previous investigations have used NIRS technology to determine changes in Sct_{O_2} during shoulder surgery in the BCP. A high incidence (80%) of cerebral desaturation events (CDEs, most commonly defined as a decrease in Sct_{O_2} values of ≥20% from baseline values) has been observed during BCP shoulder surgery under general anaesthesia with controlled ventilation and hyperventilation.[12] In contrast, a low incidence of CDE (0–10%) has been noted in patients undergoing the same procedure with regional anaesthesia, sedation, and spontaneous ventilation.[13 14]

Studies in supine awake volunteers and surgical patients have demonstrated that changes in ventilation and end-tidal carbon dioxide tension (E'_{CO_2}) result in significant alterations in Sct_{O_2} values.[9 10 15] During BCP surgery, postural decreases in Sct_{O_2} were related to both arterial pressure and E'_{CO_2}.[16] When general anaesthesia is used for BCP shoulder surgery, patients are frequently intubated and hyperventilated,[2 12] this common practice may increase the risk of CDE. The aim of this investigation was to assess the impact of two different ventilation strategies on cerebral oxygenation during BCP surgery (standard clinical practice of hyperventilation compared with normoventilation). Patients were randomized to a control 30–32 group (standard practice-ventilated to an E'_{CO_2} of 30–32 mm Hg) or a study 40–42 group (ventilated to an E'_{CO_2} of 40–42 mm Hg), and the effect of ventilation strategy on intraoperative Sct_{O_2} values, the incidence of CDEs, and clinical recovery were determined. The relationship between hyperventilation, hypotension, and Sct_{O_2} was also examined.

Methods

Study population and anaesthetic management

This randomized controlled trial was approved by the NorthShore University HealthSystem Institutional Review Board (Evanston, IL, USA) and registered at ClinicalTrials.gov (NCT01546636). Written informed consent was obtained from all patients. Seventy ASA physical status I–III patients undergoing elective shoulder arthroscopy in the BCP under general anaesthesia with controlled ventilation were enrolled. All patients were operated on by a single surgeon, and regional anaesthesia was not used (as either part of an intraoperative anaesthetic or for postoperative pain management). Exclusion criteria included: age <18 or >80 yr; orthostatic hypotension or poorly controlled hypertension; pre-existing history of cerebrovascular disease or pulmonary disease; and symptomatic cardiovascular disease.

Patients were allocated randomly to one of the two groups using a computer-generated randomization code. The individual randomization assignments were concealed in opaque envelopes until the patients entered the operating theatre. Patients in the control group were assigned a ventilation strategy designed to achieve an E'_{CO_2} of 30–32 mm Hg throughout the intraoperative period. This E'_{CO_2} concentration reflects average values observed in our clinical practice (in an observational pilot study of 20 patients) and in several academic and private practices in Illinois. Patients in the study group were assigned to a ventilation strategy with the goal of maintaining E'_{CO_2} values of 40–42 mm Hg. Clinicians providing intraoperative care were not blinded to group assignment. Patients, researchers, and clinicians administering postoperative care were blinded to group assignment.

Anaesthetic management was standardized in both study groups. Intraoperative monitoring consisted of electrocardiography, pulse oximetry, capnography, bispectral index monitoring (BIS® system, Aspect Medical Systems, Newton, MA, USA), and systemic arterial pressure via an automatic arterial pressure cuff (measurement interval every 2 min, or more frequently if clinically required) on the non-operative upper extremity. Anaesthetic induction consisted of propofol 2 mg kg^{-1}, fentanyl 100 μg, and rocuronium 0.6–0.8 mg kg^{-1}. Anaesthesia was maintained with sevoflurane 1.0–3.0% in an oxygen/air mixture [fraction of inspired oxygen ($F_{I_{O_2}}$) of 50%]. The sevoflurane concentration was adjusted to achieve BIS values of 40–60 and to maintain mean arterial pressure (MAP) within 20% of baseline values. Approximately 1–2 μg kg^{-1} h^{-1} of fentanyl was administered intraoperatively. Ondansetron was administered 30 min before the anticipated completion of the surgical procedure. Neuromuscular block was antagonized with neostigmine 50 μg kg^{-1} and glycopyrrolate 10 μg kg^{-1} when a train-of-four count of 3–4 was present.

In the control 30–32 group, an initial tidal volume of 8 cc kg^{-1} was established immediately after tracheal intubation. Respiratory rate was adjusted to achieve E'_{CO_2} concentrations of 30–32 mm Hg. In the study 40–42 group, the same tidal volume and gas mixture were used, but respiratory rate was adjusted to attain an E'_{CO_2} of 40–42 mm Hg. End-tidal carbon dioxide concentrations were monitored and recorded continuously in the operating theatre, and respiratory rate was adjusted to achieve appropriate E'_{CO_2} targets.

Per protocol, hypotension (defined as a ≥20% decrease in MAP from baseline values obtained on admission to the operating theatre) was treated with a bolus dose of phenylephrine (80 μg). The measured systemic arterial pressure was uncorrected for gravitational gradients. Additional doses of phenylephrine were administered until target arterial pressure goals were met.

Cerebral oxygenation measurements and perioperative data collection

Cerebral oxygenation was monitored continuously in operating theatre using the FORE-SIGHT system (CAS Medical Systems Inc., Branford, CT, USA). The FORE-SIGHT device is a continuous wave, spatially resolved cerebral oximeter that uses four discrete wavelengths of laser light to calculate Sct_{O_2} values. Sensors were applied bilaterally to each fronto-temporal area after cleansing the skin with alcohol. The cerebral oximetry and BIS® probes were placed in the preoperative holding area and covered with an opaque towel to prevent light interference.