The concept of critical cerebral blood flow is important and can be defined as that flow below which cerebral metabolic demand exceeds cerebral blood flow and ischemia ensues. Based on work done during halothane anesthesia, the value for critical cerebral blood flow has been accepted to be $<18 \text{ ml}\cdot100 \text{ g}^{-1}\cdot\text{min}^{-1}$. Utilizing essentially the same anesthetic techniques as in those earlier studies, we have shown what appears to be a much lower value for critical cerebral blood flow using isoflurane. In our study, five of six patients with occlusion rCBF $\leq 8 \text{ ml}\cdot100 \text{ g}^{-1}\cdot\text{min}^{-1}$ exhibited EEG changes, while no EEG changes were seen when occlusion rCBF was above that value. We suggest that this apparent decrease in critical rCBF in humans under isoflurane anesthesia may be related to the possible cerebroprotective properties of isoflurane.

In summary, this study demonstrated no correlation between transconjunctival P[CO]2 and cerebral ischemia during carotid occlusion. A lower critical rCBF was noted during isoflurane anesthesia in man than has been reported during halothane administration in similar circumstances.

**REFERENCES**


**The Influence of Hypothermic Cardiopulmonary Bypass on Neuromuscular Transmission in the Absence of Muscle Relaxants**

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Cardiopulmonary bypass attenuates neuromuscular blockade from d-tubocurarine and alcuronium\(^1\) and augments neuromuscular blockade from atracurium\(^2\) and vecuronium,\(^3\) although all of these drugs are nondepolarizing muscle relaxants. One reason these conflicting findings cannot be explained satisfactorily is the lack of control data.\(^4\) Therefore, we examined the impact of hypothermic cardiopulmonary bypass on neuromuscular transmission in the absence of muscle relaxants.

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Received from the Departments of Anesthesiology and Cardiovascular Surgery, University Hospital of Freiburg, Federal Republic of Germany. Accepted for publication September 12, 1985.
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Key words: Hypothermia. Neuromuscular transmission.

**Materials and Methods**

This study was conducted according to the institutional standards of clinical research. Ten patients, ASA classes III and IV, undergoing open-heart surgery under nitrous oxide–fentanyl anesthesia were investigated. After induction of anesthesia with flunitrazepam, 1–2 mg, and fentanyl, 0.5–1.0 mg iv, the trachea was intubated following topical anesthesia without the aid of a muscle relaxant. The administration of nitrous oxide was discontinued on initiation of cardiopulmonary bypass.

Further details on anesthesia, cardiopulmonary bypass, and monitoring were described previously.\(^4\) Neuromuscular transmission was assessed by simultaneous recording of the compound electromyogram (EMG) of the right thenar\(^4\) and twitch tension of the right adductor pollicis muscle\(^5\) in response to supramaximal train-of-four stimulation of the ulnar nerve at the wrist (pulse width 0.2 ms). The changes in the size of the EMG action potentials (measured from peak to peak) and in twitch tension secondary to cooling and rewarming were related to naso-
pharyngeal temperature (fig. 1; table 1). The results were expressed as percentages of the prebypass values (mean ± SD). Statistical significance was assessed by paired Student's t test.

RESULTS

The patients' average age was 56 ± 9 yr and the average body weight was 69 ± 7 kg. The surgical procedures were coronary artery bypass grafting (n = 6) and aortic valve replacement (n = 4). Cardiopulmonary bypass was instituted for 85 ± 29 min. Nasopharyngeal temperature before bypass was 35.1 ± 0.1°C. Both surgery and anesthesia were uneventful in all cases and, in particular, no problems resulted from not using muscle relaxants. In figure 1, despite some motion artifacts, twitch tension is shown to be moderately reduced upon cooling and to overshoot upon rewarming. In contrast, the EMG action potentials increased upon cooling and returned to normal after rewarming. Reversible twitch depression secondary to hypothermia was observed in all patients (table 1), in six of which recovery was 106–180% of control. Increasing EMG action potentials in response to cooling were recorded in eight patients, but no changes occurred in the remaining two. Table 1 summarizes the overall statistics of twitch tension and EMG, indicating that the modifications of both variables in response to changing body temperature were statistically significant.

DISCUSSION

Studies using simultaneous recording of EMG and twitch tension during hypothermic cardiopulmonary bypass in the absence of muscle relaxants have not been reported. Local cooling of the forearm and hand, in conscious volunteers, depressed the mechanical twitch response, while augmenting the voltage of the simultaneously recorded evoked compound EMG. In these individuals, at 20°C muscle temperature, both the twitch depression and the increase of EMG voltage were 20 to 50% of control.6 Though quantitatively less pronounced, our results are in line with these findings. Consequently, both twitch depression and EMG facilitation during hypothermic bypass have to be attributed to a direct effect of reduced temperature on neuromuscular transmission rather than to such factors as hemodilution, electrolyte imbalance, altered pharmacokinetics, or anesthesia. This conclusion supports previous views on the key role of hypothermia in enhancing or attenuating partial nondepolarizing neuromuscular blockade during cardiopulmonary bypass.2,4

Possible explanations of the increased EMG action potentials secondary to hypothermia include facilitated transmitter release7,8 and increased sensitivity of the postjunctional membrane to acetylcholine,9 while acetylcholinesterase inhibition is probably insignificant.10 The depression of twitch tension despite increased EMG action potentials is indicative of hypothermia-related contractile failure, which represents a condition where the evoked compound EMG cannot be used as an equivalent of mechanical twitch recording.

We conclude that hypothermic cardiopulmonary bypass facilitates neuromuscular transmission at its electrochemical level, yet compromising mechanical contractility. These effects are due to changing muscle temperature rather than to other factors related to the bypass. Modifications of partial neuromuscular blockade by hypothermic bypass14–14 are the result of muscle relaxation enhancing or interfering with the impact of hypothermia on normal

| Table 1. The Impact of Cardiopulmonary Bypass (CPB)-induced Hypothermia on the Evoked Compound Electromyogram (EMG) and Evoked Twitch Tension |
|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | Lowest Temperature | Start of Rewarming | End of Rewarming | End of CPB      | End of Surgery |
| Twitch          | 81 ± 12*          | 83 ± 15*         | 96 ± 17†        | 108 ± 18†       | 109 ± 33       |
| EMG             | 104 ± 9           | 107 ± 7*         | 103 ± 8         | 98 ± 6†         | 99 ± 5         |
| Temp °C         | 26.4 ± 1.7*       | 30.1 ± 1.1*      | 36.0 ± 0.3†     | 35.7 ± 0.4      | 33.6 ± 0.5†    |

Numbers represent per cent of control (mean ± SD, n = 10).  
* Significant difference from control.  
† Significant difference from previous value (P < 0.05).
neuromuscular transmission. Other conditions may exist where evoked twitch tension and EMG yield contradictory results.

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Anesthesiology
64:281–283, 1986

Esophageal Perforation Associated with Endotracheal Intubation

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Esophageal perforation, associated with tracheal intubation, is more likely to occur when emergency intubations are performed by inexperienced individuals. However, esophageal injury has occurred in more controlled settings. Subcutaneous emphysema, pneumothorax, cyanosis, throat pain, fever, mediastinitis, empyema, pericarditis, and death can occur as untoward sequelae. Prompt diagnosis and surgical treatment reliably prevent the delayed complications.

We describe a case of esophageal perforation during induction of anesthesia and tracheal intubation which resulted in an immediate, life-threatening airway emergency, subcutaneous emphysema, and bilateral pneumothoraces. Immediate diagnosis and surgical treatment facilitated a successful outcome.

REPORT OF A CASE

A 62-year-old woman was admitted for treatment of a small bowel obstruction. Her past medical history revealed no other significant abnormalities. She refused surgical intervention initially and received nasogastric suction. The surgical team instituted parenteral nutrition through a left subclavian catheter on the 7th hospital day.

The patient consented subsequently to abdominal exploration 10 days following admission. Before surgery, she complained of a severe sore throat and left ear pain. Left otitis media was diagnosed. Hematocrit and serum electrolyte values, as well as chest radiograph and ECG were within normal limits.

Prior to induction of anesthesia, we removed the nasogastric tube while applying suction. The patient received d-tubocurarine, 3 mg iv, and breathed oxygen for 5 min. Anesthesia was induced using thiopental, 4 mg/kg iv, and succinylcholine 1.5 mg/kg iv. Intravenous pressure was continuously applied. A laryngoscope was performed with difficulty; however, an endotracheal tube was inserted eventually with the help of a malleable copper stylet. The tip of the stylet did not protrude beyond the tip of the endotracheal tube. After inflating the cuff, an esophageal intubation was recognized immediately during attempted positive pressure ventilation. The endotracheal tube was removed. Cyanosis developed and an attempt at ventilation via a mask resulted in extensive facial and cervical subcutaneous emphysema. A second laryngoscope revealed blood in the pharynx and pharyngeal edema. Prompt endotracheal intubation and ventilation relieved the cyanosis. Anesthesia was maintained with enflurane, morrhine, and oxygen. Pancuronium provided skeletal muscle relaxation.

Auscultation of the chest revealed equal but somewhat distant breath sounds bilaterally with some scattered inspiratory rales. Subcutaneous emphysema made interpretation of chest percussion difficult. An intraoperative A-P chest radiograph revealed extensive subcutaneous emphysema, which obscured the lung fields. Mediastinal emphysema was evident. A radial arterial catheter was inserted for monitoring.

Esophagoscopy using a flexible fiberoptic endoscope demonstrated a 1.5-cm, posterior, longitudinal, perforation of the esophagus 16 cm from the teeth. This was irrigated and drained externally through a neck incision. Subsequently, an abdominal exploration and lysis of adhesions were performed without incident. Ventilation was controlled throughout the procedure. The initial arterial blood gas values were: PAO2 183 mmHg, PACO2 53 mmHg, and PH 7.53 with an FiO2 of 1.0. Addition of a 10-cm H2O peep valve and increased minute ventilation...