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Lower Esophageal Contractility Predicts Movement during Skin Incision in Patients Anesthetized with Halothane, but Not with Nitrous Oxide and Alfentanil

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The frequency of spontaneous lower esophageal contractions (SLEC) has been proposed as one measure of anesthetic depth. The authors tested the hypothesis that SLEC frequency can predict movement in response to skin incision during halothane or nitrous oxide/alfentanil anesthesia. The incidence of movement during skin incision was compared with the frequency of spontaneous lower esophageal contractions in 20 healthy patients anesthetized with halothane. Esophageal contractility was determined using the Lectron 302, which senses the pressure in a water-filled balloon positioned in the distal esophagus. Absence of SLEC in the 6 min preceding incision correlated with no movement, with one exception (n = 9). All but one patient having ≥2 SLEC in the 6 min preceding skin incision moved (n = 8) ($P < 0.01$). Sixteen additional patients anesthetized with nitrous oxide (70%) and alfentanil demonstrated no correlation between SLEC frequency and movement. These data suggest that the frequency of spontaneous lower esophageal contractions, and its ability to predict movement, depends on anesthetic type. (Key words: Anesthetic potency: minimum alveolar concentration (MAC). Anesthetics, gases: nitrous oxide. Anesthetics, intravenous: alfentanil. Anesthetics, volatile: halothane. Esophagus: contractility. Monitoring: esophageal contractility. Neuromuscular relaxants: vecuronium.)

MOVEMENT IN RESPONSE to skin incision is an objective measure of anesthetic depth and is commonly used to determine the potency of inhaled anesthetics.[1] The frequency of spontaneous lower esophageal contractions (SLEC) has been proposed as one measure of anesthetic depth.[2] We tested the hypothesis that SLEC frequency can predict movement in response to skin incision during halothane or nitrous oxide/alfentanil anesthesia.

Materials and Methods

With approval from the University of California, San Francisco, Committee on Human Research and written, informed consent from each patient, we evaluated movement during skin incision in 20 patients anesthetized with halothane and in 16 patients anesthetized with 70% nitrous oxide and alfentanil. All patients were unpremedicated ASA physical status 1 or 2, aged 18–65 yr, and scheduled for abdominal, perineal, or breast surgery. Those taking medication or having a history including esophageal or neurologic diseases were excluded from the study.

An intravenous catheter was inserted in one arm of each patient and the cuff of a Dinamap® 1846SX (Critikon Inc., Tampa, FL) blood pressure monitor was placed on the same arm. Arterial blood pressure and heart rate were determined continuously and noninvasively using a Finapres® monitor (Ohmeda Inc., Madison, WI). A Finapres® cuff was placed on one finger. Cuff size and position on the finger were adjusted until the systolic and diastolic pressures were within 10 mmHg of those determined oscillometrically on the same arm. Use of the Dinamap® was discontinued thereafter, because inflating the proximal arm cuff obstructed the continuous measurements made at the finger.

Heart rate and arterial blood pressure were recorded using strip-chart recorders calibrated prior to each use. Each patient's maximum heart rate and diastolic and systolic blood pressures during the 3 min immediately preceding skin incision were compared with the maximum values of the 3 min following. A 3-min observation period was used because maximum cardiovascular changes produced by skin incision occur within this time.[3]

In patients given halothane, orthopedic tourniquets were placed around the arm without the intravenous catheter and around both legs. Anesthesia was induced using 4% halothane, 70% nitrous oxide, and oxygen; opiates and barbiturates were not administered. Nitrous oxide was discontinued within 3 min after the start of anesthesia and the tourniquets inflated to 300 mmHg. Vecuronium (0.1 mg/kg) was administered iv, and each patient's trachea was intubated. Ventilation was controlled to maintain end-tidal carbon dioxide at ≈30 mmHg.

Movement in response to skin incision was determined using a modification of the Dixon "up-and-down" method.[4] The initial anesthetic concentration of 0.8%, an interval of 0.1%, and a group size of four patients were decided upon prospectively. The end-tidal halothane concentration administered to each patient was deter-

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mined by the response of the previous patient: anesthetic concentration was increased by 0.1% when the previously studied patient moved and decreased by 0.1% when he/she did not.

Halothane concentrations were determined by mass spectrometry (Medspect®, St. Louis, MO). End-tidal halothane concentrations were corrected for age using a factor of 0.84 in patients >55 yr and a factor of 1.1 in those <30 yr.[5] Anesthetic concentrations were kept constant for at least 15 min prior to incision to minimize the difference between alveolar and brain partial pressures.

In patients given alfentanil and nitrous oxide, orthopedic tourniquets were placed around both legs. Anesthesia was induced with 1 mg/kg thiopental, 70% nitrous oxide, and oxygen. The tourniquets were inflated to 300 mmHg, vecuronium (0.1 mg/kg) was administered iv, and a loading infusion of alfentanil, administered over 2 min, was started. When a peripheral nerve stimulator attached to one arm indicated sufficient paralysis, another 1 mg/kg thiopental was given, nitrous oxide was discontinued, and the trachea of each patient was intubated. Anesthesia was maintained with 70% nitrous oxide and an alfentanil infusion.

A modification of the Dixon method[4] was again used to determine the response to skin incision. The first patient's alfentanil dose (50 μg/kg loading infusion over 2 min, followed by a continuous infusion of 50 $\mu g \cdot kg^{-1} \cdot h^{-1}$) and the group size (four patients) were again decided upon prospectively. This dose was chosen on the basis of preliminary trials. The alfentanil dose administered to each patient was determined by the response of the previously studied patient: loading and hourly maintenance alfentanil doses were each increased by 25 μg/kg when patients moved, and decreased by 25 μg/kg when they did not. The alfentanil doses were changed by relatively large amounts (compared with the changes in halothane concentrations) because a large fraction of the total anesthetic effect in these patients was provided by nitrous oxide ($\approx$0.65 MAC), the concentration of which did not vary during the study.

In all patients, a peripheral nerve stimulator confirmed tourniquet isolation of the extremities from circulating vecuronium. Sustained tetanus during 100-Hz stimulation was considered evidence of intact neuromuscular function distal to the tourniquets. Orthopedic tourniquets used to isolate extremities from circulating muscle relaxant reportedly do not inhibit movement in response to skin incision.[6] Positive response to skin incision was defined as movement of one or more extremities occurring within 1.0 min of skin incision. The investigator who determined movement was unaware of the SLEC frequency.

Spontaneous contractions in the lower esophagus were evaluated using the Lectron 302 monitor (American Antec, Inc., Valencia, CA) which employs a 24-French esophageal stethoscope modified by the addition of a small, fluid-filled, pressure-sensing balloon at the distal end. The tip of the esophageal probe was positioned 38 cm from the teeth and then adjusted to maximize heart sounds. Water volume in the pressure-sensing balloon was adjusted until the baseline pressure was 3–5 mmHg, and threshold sensitivity was set to 15 mmHg, which is considerably higher than the changes produced by mechanical ventilation. Mechanical ventilation assured that vigorous manual ventilation would not transmit pressure exceeding the 15-mmHg threshold to the esophageal sensor.

Previous reports indicate that intraoperative SLEC frequencies are typically $\leq$0.5/min in patients anesthetized with $\approx$1 MAC of halothane.[2] Our preliminary studies suggested that lower frequencies occurred in patients given similar anesthetic concentrations before surgical incision. To increase the time resolution of these potentially low frequency signals, we prospectively chose a 6-min period of evaluation preceding skin incision. Contraction frequencies following skin incision were typically 1–3/min, and only 3 min were recorded. We did not prolong the postincision observations beyond 3 min because surgeons found the occasionally vigorous movements of the extremities disconcerting.

SLEC data were maintained in the electronic memory of the Lectron 302 during each study. The number of spontaneous contractions and the times at which they occurred were subsequently printed with a dot-matrix device. The time of skin incision was used to determine the number of contractions during the 6 min preceding and the 3 min following incision.

The ability of SLEC frequency to predict movement and changes in arterial blood pressure and heart rate following skin incision during each anesthetic technique was tested using Chi-square analysis with Yates correction for continuity. The contraction rate in the 6 min preceding skin incision was compared with the rate in the 3 min following incision using a two-tailed, paired t test. $P < 0.05$ was considered significant.

Results

Movement following skin incision in patients given halothane is plotted against the number of SLEC during the 6 min preceding incision in figure 1. Absence of SLEC in the 6 min preceding incision correlated with no movement, with one exception (n = 9). All but one patient having $\geq$2 SLEC in the 6 min preceding skin incision moved (n = 8) ($P < 0.01$).

SLEC frequency increased in the 3 min following skin incision in 14 of the 20 patients given halothane, was unchanged in three, and decreased in three others. Maximum systolic or diastolic blood pressures increased more than 10% in 18 of 19 patients, as did heart rate in 17 of

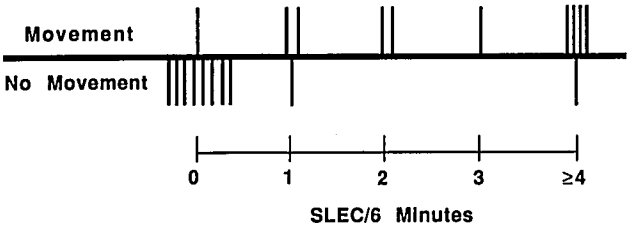

FIG. 1. The number of patients moving and not moving in response to skin incision at different spontaneous lower esophageal contraction (SLEC) frequencies during halothane anesthesia (n = 20). The investigator determining movement in patients was unaware of SLEC frequency during the 6 min preceding skin incision. Each line represents one patient. With only one exception, there was no movement in patients who had no SLEC in 6 min preceding incision (n = 9). All but one patient having ≥2 SLEC in the 6 min preceding incision moved (n = 8) ($P < 0.01$).

19 patients. The cardiovascular parameters for one patient in the halothane group were not available due to an inadvertent disconnection of the strip-chart recorders during induction of anesthesia.

Figure 2 demonstrates the good correlation between alfentanil dose and movement. All but one patient receiving 25 or 50 μg/kg as bolus and hourly infusion doses did move, while all but two patients receiving larger doses did not move following skin incision ($P < 0.05$). In figure 3, movement following skin incision in patients given alfentanil is plotted against the number of SLEC occurring during the 6 min preceding incision. There was no correlation between SLEC frequency and movement. SLEC frequency increased in the 3 min following skin incision in eight patients given alfentanil, was unchanged in five, and decreased in three others. Systolic or diastolic blood pressures increased more than 10% in 62% of patients, as did heart rate in 67% of patients.

The mean age for all patients was 42 ± 13 (SD) (range 23–65) years. Nine of the 36 patients studied were male. Surgeons denied permission to study five eligible patients, and eight others declined to participate in the study. One

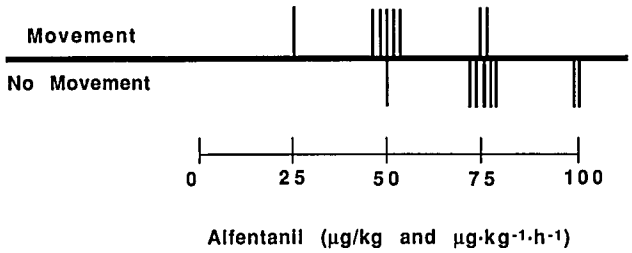

FIG. 2. Movement during skin incision plotted against different doses of alfentanil. Each line represents one patient (n = 16). All but one patient receiving 25 or 50 μg/kg as bolus and hourly infusion doses did move, whereas all but two patients receiving larger doses did not move following skin incision ($P < 0.05$).

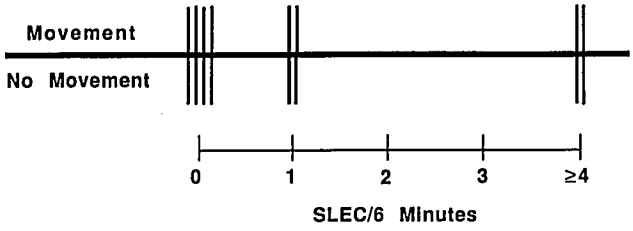

FIG. 3. Movement during skin incision plotted against esophageal contraction frequency. There is no correlation between movement and contraction frequency.

subject developed generalized rigidity, tachycardia, and cyanosis during induction; halothane was immediately discontinued and this patient was excluded from the study. We are not aware of any patient given halothane who had intraoperative recall. The patients given alfentanil were specifically questioned about recall, and all denied memory of the study period.

Discussion

Human esophageal muscle is composed of two muscle types: striated muscle in the upper quarter, smooth muscle in the lower half, and both in the middle portion.[7,8] The striated portion of the esophagus is thought to be controlled by the swallowing center in the reticular formation of the brainstem. Somatic, excitatory axons project from the nucleus ambiguus and traverse the vagi.[8¶**] Propagation of peristalsis in esophageal smooth muscle appears to rely mainly upon chemical gradients existing within the muscle itself.[8]

Three types of esophageal contraction have been identified: 1) primary contractions initiated by swallowing: these peristaltic waves start in proximal striated muscle and progress to distal smooth muscle; 2) secondary (provoked) contractions that also are propulsive, but occur in response to esophageal dilation; and, 3) tertiary (spontaneous) nonpropulsive contractions that occur only in smooth muscle.[7] Initiation of secondary and tertiary contractions is not under conscious control. The Lectron 302 does not differentiate between contraction types because it has only one pressure sensor. It does, however, consider contractions immediately following deliberate esophageal dilation as secondary.

Nonpropulsive esophageal contractions can occur spontaneously, in response to local mechanical stimulation,

¶ Snape WJ Jr, Cohen S: Control of esophageal and lower esophageal sphincter function: Neurohumoral and myogenic factors. Frontiers of Gastrointestinal Research 3:76–94, 1978.

** Christensen J: The innervation and motility of the esophagus. Frontiers of Gastrointestinal Research 3:18–32, 1978.

or, occasionally, following swallows.[9,10]†† Spontaneous contractions do not occur in brain-dead patients, indicating that cerebral function is required.[11] Nonpropulsive contractions also can be triggered by emotional stress and acoustical stimuli.[9,12,13] It is believed that these contractions are mediated by the same intramural nerves that generate propulsive esophageal contractions.

SLEC frequency is inversely proportional to end-tidal potent inhaled anesthetic concentration and, thus, a potentially useful monitor of anesthetic depth.[2,14]‡‡ However, attempts to use esophageal contractility to anticipate clinical signs of light anesthesia have been unsuccessful: neither hypertension, tachycardia, nor intraoperative movement could be predicted reliably using this method.[15,16] Nonetheless, we found that in patients given halothane, a SLEC frequency ≥ 2 per 6 min predicted movement following skin incision, and that absence of SLEC predicted absence of movement.

In contrast to the results in patients given halothane, SLEC frequency did not predict movement in patients anesthetized with nitrous oxide/alfentanil. Narcotics increase tone, but diminish motility in most segments of the gastrointestinal tract *via* mechanisms that are thought to involve both peripheral and central receptors. Thus, it is not surprising that halothane and nitrous oxide/alfentanil anesthesia affect control of spontaneous esophageal contractility differently. However, the effects of narcotics on tertiary (spontaneous) esophageal contractions have not been investigated.

Erickson *et al.* found that SLEC frequency did not predict movement in unparalyzed patients given isoflurane.[15] Isoflurane differs from halothane in causing greater cortical electroencephalographic depression. Isoflurane also may depress central control of spontaneous esophageal contractions. Our study also differed from that of Erickson *et al.* in that we used a contraction threshold of 15 rather than 20 mmHg, and that we administered vecuronium. In unparalyzed patients, the number of apparent contractions detected by the Lectron 302 may increase because the monitor cannot distinguish movement, swallowing, or coughing from signals produced by spontaneous, tertiary contractions. Consequently, the apparent contraction frequency in unparalyzed subjects may result, in part, from movement artifacts. Although movement, swallowing, and coughing are signs of light anesthesia, they may be less specific than SLEC as predictors of movement during skin incision. The study of Erickson *et al.* also differed from ours in the use of diazepam for premedication and thiamylal and succinylcholine for induction of anesthesia.

SLEC frequency increased significantly in the patients given halothane during the 3 min following skin incision, indicating that esophageal contractility increased in response to surgical stimulus. This result is consistent with previous observations that light anesthesia increases esophageal contractility. However, movement following skin incision in the nitrous oxide/alfentanil group was better correlated to alfentanil dose than to esophageal contraction frequency.

MAC BAR_{50} for halothane (the end-tidal concentration that produces <10% increases in arterial blood pressure and pulse rate in half of patients during skin incision) is ≈ 1.5 MAC.[3] End-tidal halothane concentrations were near MAC in our patients. Thus, it is not surprising that arterial blood pressure and heart rate increased more than 10% in almost every patient we studied. Heart rate and blood pressure in patients given nitrous oxide and alfentanil increased in only $\approx 60\%$ of patients, but the increases were not correlated with SLEC frequency.

Formally, "MAC" is a concept applied to inhaled anesthetics. However, the concept has also been applied to intravenous anesthesia. In these studies, movement during skin incision (or other signs of inadequate anesthesia) were compared with either administered dose[17] or plasma concentrations.[18] We observed an excellent correlation between administered alfentanil dose and movement during skin incision (fig. 2). This suggests that plasma concentrations were well correlated with administered doses. In fact, our study design does not require knowledge of plasma alfentanil concentrations, or even that concentrations be proportional to the doses we administered. We hypothesized that spontaneous esophageal contraction frequency would predict movement during skin incision. It is unnecessary to know the plasma alfentanil concentrations because the ability to predict movement should exist irrespective of plasma concentration. Because there was no correlation, esophageal contractility does not appear useful for predicting movement during skin incision in patients anesthetized with alfentanil and nitrous oxide.

Position of the esophageal pressure-sensing balloon may have affected our results. Contraction *intensity* is slightly diminished when the sensor is too proximal because there is less smooth muscle in the upper half of the esophagus; however, contraction *frequency* remains unchanged. If the sensor is in the stomach, no contractions can be detected. We positioned the modified esophageal stethoscope as one might during routine anesthesia care.

In summary, the frequency of SLEC predicted movement in response to skin incision in patients anesthetized with halothane but not with nitrous oxide and alfentanil.

†† Orlando RC, Bozymski EM, Blaylock NB: Tertiary contractions of the esophagus: A manometric study in healthy subjects (abstract). Gastroenterology 72:1109, 1977.

‡‡ Kuni DR, Greff RJ: Esophageal contractility: A new method for assessing adequacy of anesthesia. Proceedings AAMI 22nd Annual May 16–22:2894, 1987.

Previous studies[15] indicate that SLEC also does not predict movement during skin incision in unparalyzed patients anesthetized with isoflurane. These data suggest that the frequency of spontaneous lower esophageal contractions, and its ability to predict movement, depends on anesthetic type. Therefore, the extent to which SLEC is clinically useful will need to be determined for each anesthetic combination.

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