from 1959–1974, a total of 36 fires or explosions were reported, but only a third involved a flammable anesthetic. The majority of fires involved plastic, rubber, paper, fabric, and disposable items (28%), enteric gas (22%), and volatile prep solutions (8%). The source of ignition was electrocautery in 53% of the cases. Electrocautery works by emitting a radio frequency current which produces heat within the tissue. Hemostasis is achieved by occlusion of vessels with coagulated blood and tissue. When used in the “cutting” mode, the heat produced is even greater than that produced by the “coagulation” mode. The cutting current “produces intense heat, which explodes the cellular water into steam at the cautery tip.”7 Thus, electrocautery may cause fire by “local ignition” of a flammable material, which occurs when a small amount of material is heated to the ignition temperature. Electrocautery may also cause combustion by producing a spark. A spark passing through a volume of air equal to 1 mm³ can develop a temperature of 1000°C in 1 msec, adequate to ignite a flammable material.5

In addition to a fuel and a source of ignition, oxygen is necessary to produce combustion, and, in general, combustion is enhanced by both higher ambient pressures (as encountered in a hyperbaric chamber) and higher concentrations of oxygen. Dilution of oxygen by nitrogen tends to reduce combustibility, while nitrous oxide actually enhances combustion.3 In our case, large amounts of oxygen were exhaled from the patient’s mouth during percutaneous transtracheal ventilation with 100% oxygen. Since the patient’s head was entirely covered with drapes, the oxygen was probably held in place, resulting in a very high oxygen concentration near the surgical field. The ignition source was electrocautery, and the fuel was cloth drapes and a plastic glove.

Percutaneous transtracheal ventilation can be a very useful, even lifesaving, technique, and was quite efficacious in this case. Among the possible complications, fire has not been previously reported. We would make two specific suggestions to reduce the chance of fire in this setting. First, the drapes should not be allowed to cover the face, so that the exhaled oxygen will be dissipated into the room air and not accumulate under the drapes. Second, electrocautery, especially for cutting, should be avoided if at all possible when the surgical field is immediately adjacent to the oxygen source, as in this case of emergency tracheostomy.

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Neostigmine Antagonism of Vecuronium Paralysis during Fentanyl, Halothane, Isoflurane, and Enflurane Anesthesia

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The neuromuscular blocking properties of non-depolarizing muscle are enhanced by volatile anesthetics. Recently, Deslize and Bevan found that enflurane (ENFL) interfered with neostigmine antagonism of a pancuronium neuromuscular blockade. The aim of our study was to compare, with a standard dose of neostigmine, the antag-

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onism of paralysis produced by vecuronium during anesthesia maintained with nitrous oxide in oxygen and supplemented either by fentanyl (F), halothane (HAL), isoflurane (ISO), or ENFL.

PATIENT AND METHODS

Twenty-four patients (ASA Class I–II) undergoing elective surgery were studied after obtaining their informed consent. The study was approved by our Ethical Committee for Human Research. None of the patients had any clinical or biochemical evidence of hepatic or renal damage. Their age ranged from 25–50 yr (mean 35 yr) and their weight ranged from 41–80 kg (mean 69.3 kg). One hour before anesthesia, all patients received 0.2 mg/kg diazepam orally. Anesthesia was induced with methohexital 1.5 mg/kg iv. After the onset of unconsciousness, ventilation was controlled manually (50% oxygen in nitrous oxide) until the trachea was intubated following the administration of vecuronium. Thereafter, ventilation was controlled until the end of the surgical procedure. Ventilation was adjusted to produce normocapnia (end-tidal carbon dioxide about 5.0 ± 0.1%, or PaCO₂ between 35 and 37 mmHg, or P̄vCO₂ between 37 and 39 mmHg).

For maintenance of anesthesia, the patients were randomly divided into four groups of six patients each. In the F group, the patients received 5–7.5 μg/kg of F iv followed by reinjections of 1 μg/kg iv when clinical evidence of inadequate analgesia was observed. In the HAL group, the patients received HAL at end-tidal concentration of 0.8%; in the ISO group, ISO was given at end-tidal concentration of 1.25%; in the ENFL group, a ENFL end-tidal concentration of 1.5% was maintained. End-tidal concentrations of the anesthetics were measured with a piezo electric detector placed in the expiratory limb of the circle circuit. The apparatus was calibrated before each clinical session with the calibration device provided by the manufacturer and with reference halogenated anesthetics in N₂O/O₂, 2/1, ratio mixtures. The zeroing of the positive offset caused by the water vapor content of the expired gases was achieved after 20 min of anesthesia. The end-tidal anesthetic concentrations represents about 1.0 MAC if these anesthetics were given in 100% oxygen for patients aged from 25–50 yr. Heat loss from the body core and the exposed left arm was controlled by using water warming mattress (rectal temperature 37°C) and surgical sheets. Venous plasma K⁺, Na⁺, and Ca²⁺ were checked every 30 min from heparinized samples and maintained within normal values.

A force-displacement transducer (UC3 cell Statham TM), fitted with tension attenuator (UL4-20, Statham TM) and incorporated in a hand grip, was secured with adhesive tape in the patient’s left hand to measure the isometric contraction of the adductor pollicis. Following the induction of anesthesia, two 25-gauge thin-walled needles were placed subcutaneously near the ulnar nerve at the wrist and mechanical activity was induced in the adductor pollicis by square-wave pulses of 0.2 ms duration at supramaximal intensity, delivered at 0.1 Hz from a

![Fig. 1. Evolution of train-of-four recorded at 3-min intervals after administration of 40 μg/kg neostigmine once the twitch height level attained 25% of its initial value.](image)

![Fig. 2. Values of the tetanic fades recorded 15 min after administration of 40 μg/kg neostigmine. Stimulation rates 50 Hz (left side) and 100 Hz (right side); duration: 5 sec. *P < 0.05; **P < 0.01. Kruskall Wallis test.](image)
Grass S88 TM stimulator. The resulting analog signals were amplified and registered on a polygraph recorder. After a 3-min period of control of the twitch height, vecuronium 100 \( \mu \)g/kg was given iv, and the trachea was intubated once the twitch height had been obliterated. Every time the twitch height regained 25% of its baseline height, a supplementary iv injection of vecuronium, 20 \( \mu \)g/kg, was given until completion of surgery. A delay between 60 and 90 min was allowed between the start of anesthesia and the neostigmine/atropine administration to limit the time-dependence increase in sensitivity of the neuromuscular junction to non-depolarizing relaxants during enflurane anesthesia.\(^{12}\) Vecuronium paralysis was antagonized with 40 \( \mu \)g/kg neostigmine and 15 \( \mu \)g/kg of atropine iv when twitch tension had returned to 25% of the control twitch tension. After the administration of the neostigmine/atropine mixture, the following parameters were observed during a 15-min period: twitch height was measured every 10 s, and train-of-four, 2 Hz, every 3 min. Immediately thereafter, tetanic fades, 100 and 50 Hz, 5 s duration, 1 min apart, were randomly assessed. The degree of tetanic fade was calculated as the ratio between the residual muscular activity observed after 5 s of stimulation and the maximal response registered. The administration of the inhaled anesthetics was terminated when all these tests were achieved. Statistical analysis of the data were performed with the Kruskal-Wallis test according to SPSS package programs.\(^{13}\) The statistical comparisons were considered significant at \( P < 0.05.\)

**RESULTS**

No significant differences were found between the patients of the four groups regarding their ages, weights, and heights. The twitch height recovery patterns were quite similar in the four groups. At the end of the observation period, no significant differences were noted when the F group was compared with the other three groups, and all were 97% or more.

Figure 1 illustrates the evolutions of the trains-of-four observed in the different groups. Before neostigmine administration, the mean train-of-four ratio of the F groups was 7%; whereas, in the other groups, this value was always equal to zero (\( P < 0.01.\)). Fifteen minutes following neostigmine administration, a train-of-four of 86 ± 4% (mean ± SEM) was observed in the F groups. This value was not significantly different from the final trains-of-four observed in the other three groups.

After the 50Hz stimulation test, the value noted for the ENFL group was significantly lower (73 ± 7%) if compared to the F group (96 ± 3% [\( P < 0.05.\)]). At 100 Hz, significant differences were recorded between the ENFL group (87 ± 12% [\( P < 0.01.\)]) and the ISO patients (57 ± 15 [\( P < 0.05.\)]) in comparison to the F patients, where a mean score of 91 ± 4% was obtained (fig. 2).

**DISCUSSION**

Volatile anesthetics have depressant effects on the neuromuscular junction as evidenced by recording the indirectly elicited adductor pollicis muscle activity at high frequencies. A very slight tetanic fade—80% of the initial value—can be observed only for high stimulation rates (e.g., above 120 Hz) during anesthesia maintained with ENFL if a concentration exceeding 1 MAC is maintained.\(^{14}\) Furthermore, halogenated anesthetics shift to the left the dose/effect curve of various nondepolarizing muscle relaxants.\(^{15-16}\) For vecuronium, Rupp et al.\(^{17}\) found an ascending order of potency with HAL < ISO < ENFL.

Besides these well-documented interactions, Desile and Bevan\(^{6}\) have shown, with train-of-four measurements, that, during ENFL anesthesia, the antagonism by neostigmine of pancuronium paralysis was incomplete for more than 30 min. As evidenced by the tetanic fade measurements, the present study confirms impairment of the reversal of pancuronium paralysis by neostigmine for more than 15 min during 1.0 MAC ISO or ENFL anesthesia with 66% \( \text{N}_2\text{O}.\)

Nevertheless, in contrast to Desile and Bevan’s study, the present results showed that, after a delay of 15 min, mean train-of-four measurements above the level of 75% were obtainable in all the groups studied. These results reflect the faster reversal of vecuronium paralysis as compared to the paralysis produced by pancuronium following succinylcholine. Another difference between Desile and Bevan’s study and ours was the spontaneous prereversal twitch height recovery at the time the reversal was performed—10% versus 25% in our study. This factor must be considered, because twitch height and train-of-four recovery rates are dependent on the prereversal twitch height recovery level.\(^{3,18}\)

Some authors have proposed 75% train-of-four level as the reference instrumental test for acceptable clinical recovery in case of paralysis induced with non-depolarizing relaxant. This train-of-four level is often associated with a near-normal vital capacity or sustained head lift test in a great majority of patients receiving either narcotic/\( \text{N}_2\text{O} \) or HAL/\( \text{N}_2\text{O} \) anesthetics.\(^{19,20}\) As evidenced in our ISO and ENF series in our study, the coexistence, in adductor pollicis muscle/cubital nerve junction, of a train-of-four above 75% and marked tetanic fades, indicates that, in man, a train-of-four level above 75% is not obligatorily a sign of the return to a near-normal function of some neuromuscular junctions, including the cubital adductor pollicis muscle. Unfortunately, the relationships between the results obtained after all stimulation patterns considered in this study and adequate ventilation during
and following administration of the volatile anesthetics have not been determined so far. This study has pointed out that the antagonism of vecuronium paralysis by neostigmine will probably restore, within 15 min, train-of-four ratios above 75%. Nevertheless, it is quite evident that the safety margin of the neuromuscular transmission is not always reset by neostigmine at the same level, depending on the nature of the anesthetic regimen used. According to this, the observation of different motoneuronal stimulation patterns, including high tetanic stimulation rates, seems mandatory in any clinical trial devoted to detect slight residual impairments of the neuromuscular transmission.

From a practical point of view, one must underline that the present results may not reflect exactly the day-to-day routine where, at the end of anesthetics, the endtidal concentration of the halogenated vapors are generally decreased below 1 MAC when paralysis reversal with anticholinesterasic agents is performed.

In conclusion, we found mean trains-of-four above 75% at 15 min following the administration of 40 μg/kg neostigmine iv given at 25% of spontaneous twitch height recovery during anesthesia with F/NeO: HAL, ENFL, or ISO. Depending on the halogenated anesthetic received, the recording of a train-of-four above 75% is not necessarily accompanied, for the adductor pollicis muscle, by the recovery of a normal neuromuscular transmission, as profound tetanic fades are yet recordable, especially during ENFL and ISO anesthesia.

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Erratum