In a prospective study of neurosurgical procedures, Marshall and Bedford\(^1\) have speculated that early detection of VAE prompted attempts at air removal before large volumes were embolized, and, hence, only small amounts were recoverable. They suggested that a pulmonary artery catheter is useful for both the diagnosis and treatment of VAE. In our case of VAE, we were also unable to remove significant amounts of air from either the central venous or PA ports of the pulmonary artery catheter, and must conclude that this is not an effective therapeutic modality.

In summary, we have found that significant air embolism is possible in the system of veno-venous bypass most frequently used in OLT; surgeons, anesthesiologists, and perfusionists should be aware of this possibility for adequate prevention, monitoring, and therapy. The risks of \(\text{N}_2\text{O}\) use during veno-venous bypass appear to outweigh its benefits, and, while a pulmonary artery catheter is effective in detecting VAE, it should not be relied on as an effective method of removing embolized venous air.

REFERENCES


Anesthesiology

Sensitivity of the Adductor Pollicis and Diaphragm Muscles to Atracurium in a Hemiplegic Patient


Resistance to the action of non-depolarizing muscle relaxants (NDMRs) occurs in patients with upper motor neuron lesions,\(^1,2\) and may extend to the normal, as well as the paretic, limbs.\(^3\) Disuse atrophy is also associated with resistance to NDMRs. In dogs, decreased sensitivity to pancuronium has been found in an immobilized leg compared with the contralateral limb.\(^4\) The diaphragm is normally resistant to the action of NDMRs,\(^5,6\) and, in guinea pigs' diaphragm, sensitivity to d-tubocurarine does not change with limb immobilization.\(^7\) Thus, it might be predicted that the sensitivity of the diaphragm may be normal in patients who are hemiplegic because of a cerebrovascular accident.

We report a case where neuromuscular function was monitored at the diaphragm and at both adductor pollicis muscles in a patient with hemiplegia. Dose-response curves of atracurium were determined at these three sites.
FIG. 1. Cumulative dose-response curve for atracurium, showing percent depression of response to first stimulus in train-of-four (logit scale) versus dose (log scale), for diaphragm and both adductor pollicis muscles.

CASE REPORT

A 53-yr-old, 74-kg man was admitted for repair of a right inguinal hernia. He was taking no chronic medications. Three years previously, he had suffered a cerebrovascular accident involving the right hemisphere. Physical examination revealed spasticity on the left side, with decreased motor strength and hyperreflexia. Hemoglobin, blood urea, serum electrolytes, and chest radiograph were normal, as was the ECG apart from a sinus tachycardia. Informed consent to stimulate the right phrenic and both ulnar nerves was obtained from the patient.

He was given atropine 0.007 mg/kg and morphine 0.1 mg/kg im 1 h before the start of the procedure. Anesthesia was induced with thiopental 4 mg/kg iv. Then the patient breathed nitrous oxide 70%, oxygen 30%, and halothane until tracheal intubation was accomplished without the use of muscle relaxants. Following intubation, the inspired halothane concentration was set at 0.5%. The force of contraction of both adductor pollicis muscles was measured in response to supramaximal train-of-four stimulation of the ulnar nerve at the elbow. Similarly, diaphragmatic EMG response to stimulation of the right phrenic nerve in the neck was recorded. After control measurements, an initial dose of atracurium 0.1 mg/kg was given. When both adductor pollicis and diaphragm responses were stable, defined as three equal consecutive first twitch heights, increments of 0.05 mg/kg atracurium were administered until the diaphragmatic EMG response to the first stimulation of the train-of-four was depressed by more than 90%. To allow for the relatively rapid elimination of atracurium, an infusion of the drug was started once a stable response was seen, and the rate of infusion was increased after each succeeding set of measurements. Based on pharmacokinetic data, the hourly rate of infusion was set at three times the total dose already given. This modification of the cumulative dose technique has been shown to yield results indistinguishable from those obtained from the administration of single doses to a large number of patients.

Cumulative dose-response curves were constructed for each of the three sites by plotting the logit transformation of the first twitch response against the logarithm of the cumulative dose (without the dose infused). The adductor pollicis on the paretic side was more resistant to atracurium than on the normal side (fig. 1). The difference was approximately 30%. The diaphragm was more resistant than the normal adductor pollicis, but had a sensitivity closer to that of the paretic adductor pollicis. The ED50s for the normal adductor pollicis, paretic adductor pollicis, and diaphragm were 128, 171, and 164 μg/kg, respectively. Corresponding values for ED90s were 191, 240, and 308 μg/kg, respectively.

Sixty-six minutes after the administration of the first atracurium dose, the first twitch height of the unaffected adductor pollicis had returned to 10% of control. Corresponding values were 49% for the contralateral adductor pollicis and 43% for the diaphragm. Train-of-four stimulation produced only one visible twitch at the adductor pollicis on the normal side. Train-of-four ratio was 14% at the contralateral adductor pollicis and 15% at the diaphragm. Neostigmine, 3.0 mg (0.04 mg/kg), was administered with atropine 1.2 mg iv. Recovery was much slower in the normal adductor pollicis compared with the other two muscles (table 1). Eight minutes after neostigmine was given, halothane and nitrous oxide administration was discontinued. A few minutes later, the patient was breathing spontaneously, and his trachea could be extubated.

DISCUSSION

The data from this patient confirm previous reports of the relative resistance of paretic limbs to NDMRs. This change in sensitivity may be due to both increased chemosensitivity of the muscle and axonal sprouting from existing neural elements. In both hemiplegic patients and immobilized guinea pigs, the non-hemiplegic or non-immobilized limb also displayed decreased sensitivity to NDMRs. In the case of the guinea pig, this decreased sensitivity did not extend to the diaphragm. This would also appear to be the case in our patient. In normal subjects, the potency ratio of diaphragm to adductor pollicis for NDMRs is approximately 2:1. In our patient, the ratio of ED50s and ED90s of diaphragm to adductor pollicis on the unaffected side was 1.3:1 and 1.6:1, respectively. The ratio of ED50s and ED90s of the diaphragm to the paretic adductor pollicis was 0.96:1 and 1.3:1, respectively. Therefore, while it is unlikely that the sensitivity of the diaphragm was affected by the patient's disease, it is possible the adductor pollicis muscle on the unaffected side might have undergone a slight decrease in sensitivity. Clearly, the

<table>
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<tr>
<th>TABLE 1. Recovery Pattern After Neostigmine, 0.04 mg/kg</th>
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<td>Minutes After Neostigmine</td>
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<td>Adductor pollicis (paretic side)</td>
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paretic adductor pollicis was more resistant than normal.

Cumulative dose-response curves are extremely useful to determine the potency of non-depolarizing muscle relaxants. The technique is especially well suited in this case, because one could obtain several points from three different muscles in the same individual. However, cumulative dose-response techniques may not be as accurate for atracurium as for longer-acting drugs because of its relatively rapid elimination. The problem can be largely overcome if an infusion is started when the effect of each dose is maximum and adjusted to keep neuromuscular blockade constant. Adductor pollicis dose-response relationships using this technique are similar to those obtained with single-dose administration to a large number of patients.

The force of isometric contraction of both adductor pollicis muscles was recorded, whereas the electromyographic (EMG) response of the diaphragm was measured. This was done because it is difficult to obtain an isometric contraction of the diaphragm, and measurement of transdiaphragmatic pressure involves invasive procedures. Nevertheless, it appears that EMG correlates very well with transdiaphragmatic pressure measurements, at least in awake volunteers with a closed glottis.

This case report also indicates that muscles which are normally resistant to neuromuscular blockers, such as the diaphragm, respond very well to the action of non-stigmatic. The same is true of pathologically resistant muscle. Thus, recovery in a sensitive muscle is a reliable indicator of recovery in a resistant muscle. From a clinical standpoint, our findings reinforce the importance of using the normal limb for neuromuscular monitoring in patients with hemiplegia. Small to moderate degrees of neuromuscular blockade can be better assessed if a relatively sensitive muscle is used. In addition, the relationship between the diaphragm and the adductor pollicis of the unaffected side more closely resembles that observed in normal subjects.

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