over direct laryngoscopy in terms of hemodynamic stability, because the duration of laryngoscopy and experience of the personnel involved were identical in the No. 2 Miller and "light wand" groups, as were the responses to laryngoscopy. Any advantage or disadvantage of the No. 3 Macintosh blade compared to either the No. 2 Miller or "light wand" cannot be discerned from the present study.

In conclusion, we have found that indirect laryngoscopy with the lighted stylet compared to direct laryngoscopy offers no advantage or disadvantage in terms of hemodynamic stability. Rather, the duration of laryngoscopy is an important variable associated with the magnitude of the increase in heart rate and mean arterial pressure. Endotracheal intubation then provides a further non-specific autonomic stimulus. Indirect laryngoscopy should be selected for anatomic, rather than hemodynamic, considerations.

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Postoperative Neuromuscular Blockade: A Comparison Between Atracurium, Vecuronium, and Pancuronium

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Reports from Denmark[1] and Australia[2] have shown that postoperative residual neuromuscular blockade is common. On arrival in the recovery room, 30 of 72 patients (42%) in Copenhagen and 21 of 100 (21%) in Victoria had train-of-four ratios of less than 0.7.

However, anesthetic practice in North America differs in several respects from that described in those reports. First, neuromuscular activity was not monitored during surgery in any patient in the two studies. Secondly, both investigations were completed before the intermediate-acting muscle relaxants, atracurium and vecuronium, were available, so that only long-acting nondepolarizing neuromuscular blocking drugs were used, often in high doses. Third, halothane was the most commonly used anesthetic agent. Supplementation of anesthesia with agents such as enflurane and isoflurane, which produce greater potentiation of neuromuscular relaxants[3,4] and impaired recovery,[5,6] was used less frequently[1] or not at all.[2]

The present study was designed to determine the incidence of residual neuromuscular blockade in 150 unselected patients who had received nondepolarizing muscle relaxants during surgery. Attempts were made to identify causative factors in patients demonstrating a persistent neuromuscular blockade.

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TABLE 1. Demographic Data, Divided According to Choice of Neuromuscular Blocking Drug

	n	Sex (M:F)	Age (yr)	Weight (kg)	Height (cm)
Pancuronium	47	24:23	50.7 ± 2.3	70.0 ± 1.9	165.7 ± 1.3
Atracurium	46	15:31	44.7 ± 2.8	66.9 ± 1.7	165.2 ± 1.9
Vecuronium	57	21:36	42.9 ± 2.2	66.7 ± 2.3	162.8 ± 1.6
Total	150	60:90			

MATERIALS AND METHODS

One hundred and fifty unselected adult patients were studied as part of an anesthetic audit that had been approved by the Hospital Ethics Committee. On the days chosen for study, all patients who had received the nondepolarizing neuromuscular blocking drugs, atracurium, vecuronium, or pancuronium, and who were expected to resume spontaneous breathing after surgery were included. The patients ranged in age from 17 to 83 yr, and in weight from 45 to 130 kg. There were 60 male and 90 female patients. The choice of drugs used for premedication, anesthesia, and neuromuscular blockade and its reversal was made by the anesthesiologist, who was unaware that the patient was to be assessed in the recovery room.

On arrival in the recovery room, and as soon as the anesthesiologist had left, the ulnar nerve was stimulated supramaximally, with trains-of-four square pulses of 0.2 ms in duration, delivered at a frequency of 2 Hz for 2 s and repeated every 12 s. The hand and forearm were immobilized in a splint and the force of contraction of the adductor pollicis was measured with a force-displacement transducer (Grass® FT.10) and recorded on paper. Trains were applied until a stable assessment was made, and this usually took less than 2 min. The train-of-four (TOF), T4/T1, the ratio of the force of the fourth twitch to the force of the first twitch in each train, was expressed as a percentage.

Clinical assessment of recovery (ability to lift head for 5 s, hand grip, protrude tongue, and open eyes) was made in all patients who were sufficiently awake and cooperative. The patient's response was recorded as "normal" or "weak."

Results are expressed as mean values (±SEM). Comparisons between groups were made using Chi-square analysis and Student's *t* test. When comparing three groups, analysis of variance was made, and, if a statistically significant difference was found, the Bonferroni correction was applied.[7] Results were considered statistically significant when the *P* value was 0.05 or less.

RESULTS

The patients were divided into three groups according to the choice of neuromuscular blocking drug, atracurium, pancuronium, or vecuronium. There were no significant differences in the ages, weights, or heights among the groups. Overall, more women than men were studied, although the pancuronium group contained more men than women (table 1).

Premedication consisted of diazepam 5–10 mg (n = 57), morphine 5–10 mg (n = 25), or meperidine 25–75 mg (n = 24). Forty-five patients received no premedication. Anticholinergic drugs were given to 48 patients. Anesthesia was induced with thiopental (2–7 $mg \cdot kg^{-1}$) (n = 115) or methohexital (1–2 $mg \cdot kg^{-1}$) (n = 35). Succinylcholine (1–1.5 $mg \cdot kg^{-1}$) was used in 98 patients. The rest received either atracurium (n = 29), vecuronium (n = 15), or pancuronium (n = 8) to facilitate tracheal intubation. Anesthesia was maintained with nitrous oxide (50–70%) and fentanyl, and supplemented with either enflurane (0.5–2% inspired) (n = 81) or isoflurane (0.25–1.5%) (n = 56). Halothane was not administered, and 13 patients received no inhalational anesthetic.

Muscle relaxation was provided with intermittent iv doses of pancuronium, atracurium, or vecuronium. The total doses given were 5.0 ± 0.05 mg, 34.3 ± 2.7 mg, and 6.6 ± 0.7 mg, respectively. The use of a peripheral nerve stimulator was noted in 74% of patients. Its response was assessed either visually or manually. At the end of the procedure, edrophonium (0.3–1 $mg \cdot kg^{-1}$) (n = 50) or neostigmine (0.02–0.07 $mg \cdot kg^{-1}$) (n = 84) was given with atropine or glycopyrrolate. Sixteen patients were not given reversal agents.

The duration of anesthesia was significantly longer in patients who had received pancuronium than those who had received atracurium or vecuronium (table 2). The mean train-of-four measured in the recovery room, 12–16 min after administration of reversal agents, was decreased significantly in those patients who had received pancuronium compared with atracurium or vecuronium ($P < 0.01$) (table 2). Most of the patients who had received atracurium or vecuronium had a TOF exceeding 90%, whereas recovery was less complete in the pancuronium group (fig. 1). Neuromuscular monitoring was noted to have been used during anesthesia in 22 of the 24 patients who had TOF <70% on arrival in the recovery room.

TABLE 2. Duration of Anesthesia and Residual Block

	n	Dose mg/kg/h	Duration of Block (Min)	Time of Testing after Reversal (Min)	TOF (%)	TOF <70% (n)
Pancuronium	47	0.03 ± 0.002	146.9 ± 10.7*	14.9 ± 1.0	74.4 ± 2.7*	17*
Atracurium	46	0.37 ± 0.03	101.0 ± 9.1	13.0 ± 1.0	93.2 ± 1.1	2
Vecuronium	57	0.06 ± 0.004	106.3 ± 7.5	13.4 ± 1.0	89.1 ± 1.9	5

* $P < 0.01$ *versus* atracurium and vecuronium.

One hundred and thirteen patients (76%) were sufficiently awake and cooperative to be evaluated clinically. In these patients, the relationship between clinical testing and TOF measurement in the recovery room is shown in figure 1. Clinical weakness was detected in at least one of the four tests in nine patients. This occurred with TOF which ranged from 32 to 85%. Eight of these patients had received pancuronium (table 3). Clinical testing was only possible in cooperative patients. There was no difference among muscle relaxants in the frequency of patients who were asleep, uncooperative, or awake in the recovery room.

A greater proportion of patients in the pancuronium group received enflurane, and fewer received isoflurane, than in the atracurium and vecuronium groups. After correcting for this unequal distribution, there was no significant difference in the frequency of TOF <70% between the two inhalational agents ($0.05 < P < 0.1$). Also, the choice of anticholinesterase, edrophonium or neostigmine, did not affect the frequency of residual paralysis.

DISCUSSION

The incidence of impaired recovery of neuromuscular activity following the use of pancuronium and its reversal in the present study (36%) was similar to previous reports from Denmark (42%)[1] and Australia (21%).[2] This occurred despite almost universal use of neuromuscular monitoring throughout anesthesia and smaller mean doses of pancuronium (0.03 *vs.* 0.05[1] $mg \cdot kg^{-1} \cdot h^{-1}$) (table 2). However, the incidence was decreased considerably in patients who had received the newer, intermediate-duration neuromuscular blocking drugs, atracurium and vecuronium.

The data in the present study were obtained from

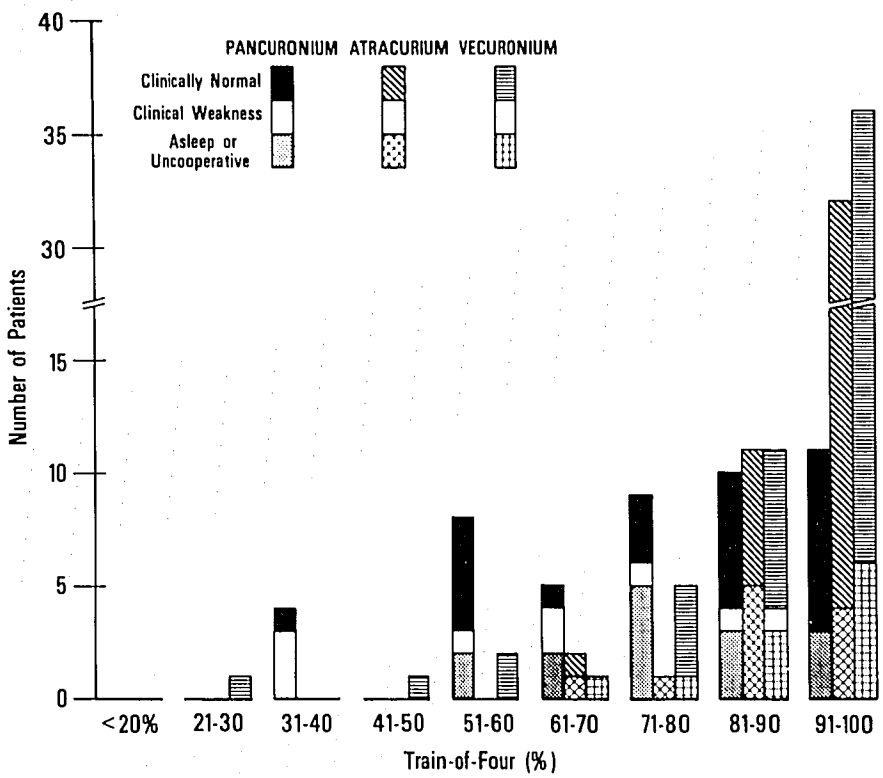

FIG. 1. Relationship between TOF and muscle weakness in 150 patients on arrival in recovery room.

TABLE 3. Clinical Assessment and TOF %

	Asleep or Uncooperative		Awake and Cooperative			
			All Tests Normal		One or More Abnormal	
	n (%)	TOF	n (%)	TOF	n (%)	TOF
Pancuronium (n = 47)	15 (32.1)	79.3 ± 3.6	24 (51.1)	73.9 ± 4.7	8 (17.0)	57.1 ± 7.2
Atracurium (n = 46)	11 (23.9)	89.8 ± 2.9	35 (76.1)	94.0 ± 1.2	0 (0)	
Vecuronium (n = 57)	11 (19.3)	89.3 ± 3.7	45 (78.9)	89.7 ± 2.0	1 (1.8)	85

patients in a clinical context. Individual anesthesiologists were allowed a choice with respect to drugs used and their doses for premedication, anesthesia, and neuromuscular blocking and its reversal. Such a design has the advantage of making observations relevant to clinical anesthesia. However, it also suffers from the disadvantages that can be avoided in a tightly controlled study. For example, variation in the dose and timing of administration of inhalational anesthetic agents, and neuromuscular blocking drugs and their reveral agents may all modify the rate of recovery of neuromuscular activity. Differences between techniques may be difficult to identify. For example, the impaired recovery in the pancuronium group may have been caused by the longer durations of surgery, which required prolonged neuromuscular block, and not by the choice of neuromuscular blocking drug. Failure to demonstrate an increased incidence of impaired recovery with time does not exclude this possibility. Similarly, it is not possible to determine how neuromuscular monitoring was used during anesthesia. Recording the frequency of use from the anesthetic record is of limited value. Consequently, the conclusions drawn from the results must be interpreted with care. Nevertheless, the high incidence of measurable muscle weakness merited attention.

The rate of recovery from nondepolarizing blocking drugs after their reversal with anticholinesterases is dependent upon the spontaneous rate of recovery and its augmentation by reversal drugs. Studies in which anticholinesterases were given during the course of a continuous infusion of relaxant demonstrated that vecuronium is not displaced any more easily than pancuronium.[8] Thus, the more rapid recovery observed after atracurium[9] or vecuronium[10,11] is a consequence of more rapid spontaneous recovery.[11] The present study demonstrates that this results in measurable differences in neuromuscular function when patients arrive in the recovery room. The small differences in reversibility between atracurium and vecuronium that have been described in controlled studies[12] were not demonstrable in the present study. Similarly, no differences could be related to the duration of neuromuscular blockade, the choice of inhaled anesthetic, or the use of either edrophonium or neostigmine. Thus, although the continued administration of enflurane throughout reversal has been associated with impaired return of activity,[5,6] this effect may not be of clinical importance when anesthetic vapors are gradually tailed off towards the end of surgery. The failure to demonstrate a difference between patients whose muscle relaxation was reversed with edrophonium or neostigmine suggests that all the patients had sufficient recovery of neuromuscular activity, so that the impaired reversal of intense blockade with edrophonium was not observed.[13–15]

A train-of-four of 70% was chosen as the critical value, because studies in awake volunteers have demonstrated impaired ventilatory function at values below this.[16] However, it is uncertain why ventilation is altered at this level because diaphragmatic activity is preserved.[17–19] Presumably, other muscle groups, particularly those of the upper airway,[20] have greater importance. It has long been suspected that the use of neuromuscular blocking drugs might be responsible for postanesthetic morbidity.

Clinical testing was useful in recognizing only six of 18 awake patients who had TOF of <70% on arrival in the recovery room. Conversely, three patients with TOF >70% demonstrated clinical weakness. This suggests that careful neuromuscular monitoring would improve the ability to recognize postoperative weakness. However, the failure of the anesthesiologist to recognize impaired neuromuscular activity in the present investigation suggests that neuromuscular monitoring needs to be more rigorous. It is not possible, from this study, to determine whether either TOF or clinical testing was appropriate. If the purpose of reversal of neuromuscular blocking drugs is to restore neuromuscular activity, then the presence of detectable weakness represents therapeutic failure.

Earlier studies[21] were dismissed on account of study design and lack of confirmation. Nevertheless, some recent epidemiological investigations have incriminated persistent postoperative paralysis as an important cause of anesthetic morbidity and mortality.[22] This and other studies[1,2] suggest that impaired neuromuscular activity after the long-acting neuromuscular blocking drugs is so common that ventilatory impairment must also occur.

In summary, impaired neuromuscular activity assessed by TOF monitoring was found in 17 of 47 patients given pancuronium followed by its reversal during anesthesia. The frequency of impairment was reduced when the neuromuscular blocking drug was either atracurium, two of 46, or vecuronium, five of 57. It is recommended that rigorous neuromuscular monitoring is necessary to recognize the potentially dangerous persistent postoperative paralysis, especially if long-acting drugs are used.

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Positioning the Air Aspiration Pulmonary Artery Catheter Introducer Sheath by Intravascular Electrocardiography

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Some anesthesiologists prefer a pulmonary artery catheter for monitoring during sitting neurosurgical procedures.[1–3] Pulmonary artery catheters provide information about circulatory dynamics, indicate when a right-to-left atrial pressure gradient exists (risk for arterial air embolism), and indicate when venous air embolism occurs. However, in the event of venous air embolism, the pulmonary artery catheter is not well suited for aspiration of large amounts of air from the right atrium, because of the small lumen of the atrial port. The inabil-

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