REVIEW ARTICLE

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# *Clinical Pharmacology of Vecuronium and Atracurium*

*Ronald D. Miller, M.D.,* Stephen M. Rupp, M.D.,† Dennis M. Fisher, M.D.,‡ Roy Cronnelly, Ph.D., M.D.,§ Mark R. Fahey, M.D.,† Yung J. Sohn, M.D.¶*



CONTENTS



VECURONIUM (Norcuron™, ORG NC45) and Atracurium (Tracrium™, BW 33A) are two new nondepolarizing neuromuscular blocking drugs that have durations of action between those of succinylcholine and pancuronium. Although part of the developmental pharmacology has been described previously,[1,2] the complete clinical pharmacology, which provided the basis for approval of these two drugs by the U. S. Food and Drug Administration, has not been summarized. Vecuronium and atracurium will be compared with three other neuromuscular blocking drugs, succinylcholine, pancuronium, and *d*-tubocurarine.

* Professor and Chairman of Anesthesia, and Professor of Pharmacology.

† Assistant Professor of Anesthesia.

‡ Assistant Professor of Anesthesia and Pediatrics.

§ Assistant Professor of Anesthesia and Pharmacology.

¶ Associate Professor of Anesthesia and Pharmacology.

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Address reprint requests to Dr. Miller: Department of Anesthesia, S-436, University of California, School of Medicine, San Francisco, California 94143.

## Developmental Chemistry

Savage *et al.*[3] are responsible for the manipulation of the steroid nucleus that resulted in the development of many neuromuscular blocking drugs, the most successful being the bisquaternary pancuronium (fig. 1). To provide a nondepolarizing neuromuscular blocker with a more rapid onset of action and shorter duration of action than that of pancuronium, the monoquaternary vecuronium was developed. Two nitrogen atoms are required for both neuromuscular blockers to retain potency. Also, the acetylcholine fragments in the ring D of both pancuronium and vecuronium make them among the most potent of all the steroid muscle relaxants studied[3] (fig. 1). This rigid-trapped fragment probably interacts with the nicotinic cholinergic receptor and must have a low affinity for muscarinic receptors. Although both vecuronium and pancuronium are hydrophilic, vecuronium is slightly more lipophilic because it is a monoquaternary rather than bisquaternary compound. Because of this increased lipophilicity, vecuronium was predicted to have a different pharmacokinetic and pharmacodynamic profile than pancuronium,[3] as described in the pharmacokinetic section below. Increased lipophilicity should enhance penetration of membranes and could alter vecuronium's route of elimination as compared with pancuronium, which proved to be the case.

Stenlake *et al.*[4] used a different principle in developing a neuromuscular blocking drug having a short duration of action. Basically, the duration of action could be short if the neuromuscular blocking drug spontaneously degraded to inactive breakdown products. Thus, atracurium was developed. This quaternary ammonium compound breaks down in the absence of plasma enzymes through Hofmann elimination and to a lesser extent ester hydrolysis (fig. 2). Hofmann elimination is a nonbiologic method of degradation that occurs at a physiologic temperature and *p*H. By lowering temperature

and *p*H, the rate of this reaction is decreased. Ester hydrolysis does not require pseudocholinesterase and is facilitated by an acid *p*H. The major breakdown products are laudanosine and a related quaternary acid, neither of which has neuromuscular blocking effects.[5]

## Potency

The potency of vecuronium is equal to or slightly greater than that of pancuronium; the ratio of their potencies range from 1.0 to 1.74.[6-13] Atracurium is less potent than pancuronium, the ratios of their potencies ranging from 0.25 o 0.33.[13-15]

When dose–response curves are constructed, the $ED_{90}$ or $ED_{95}$ (*i.e.*, the doses of neuromuscular blocking drug that depress twitch tension 90% or 95%) can be derived. This dose usually provides adequate relaxation in an anesthetized patient. There is no significant clinical difference between the $ED_{90}$ and $ED_{95}$, but unfortunately investigators were not uniform in which values were reported. Thus, to compare the work of all investigators, both the $ED_{90}$ and $ED_{95}$ must be reported by us. However, the $ED_{90}$ or $ED_{95}$ varies, depending on several factors, including the anesthetic and the method of peripheral nerve stimulation (*e.g.*, single twitch tension, train-of-four). Thus, the $ED_{90}$s range from 0.023 to 0.044 $mg \cdot kg^{-1}$ for vecuronium[6,16] and from 0.10 to 0.25 $mg \cdot kg^{-1}$ for atracurium.[17-20]

The method of constructing a dose–response curve will alter the conclusions regarding short-acting drugs such as vecuronium and atracurium more than for longer-acting drugs such as pancuronium. The traditional method is to administer a single bolus of neuromuscular blocking drug and to quantify the resulting neuromuscular blockade. One dose is given to each patient. Another method that requires fewer patients is to determine "cumulative dose–response" curves. With this method, a small dose of neuromuscular blocking drug is given and the resulting twitch depression observed. When no further change occurs for three or four twitches, an additional dose is given and its effect quantified. Additional doses of neuromuscular blocking drug are given until twitch height is depressed more than 90%. If three or four doses are given, then a complete dose–response curve can be constructed for each patient. For the longer-acting muscle relaxants, such as pancuronium, the single-bolus and cumulative

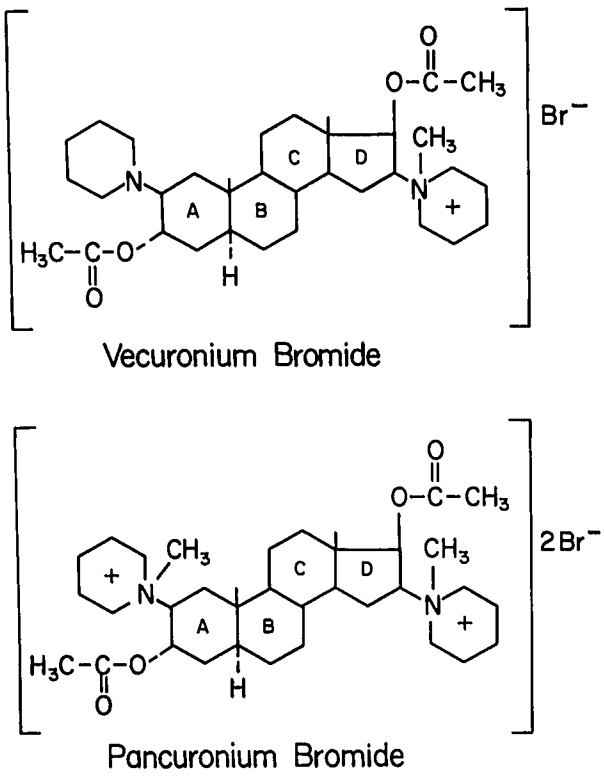


FIG. 1. Comparative chemical formulas for pancuronium and vecuronium.

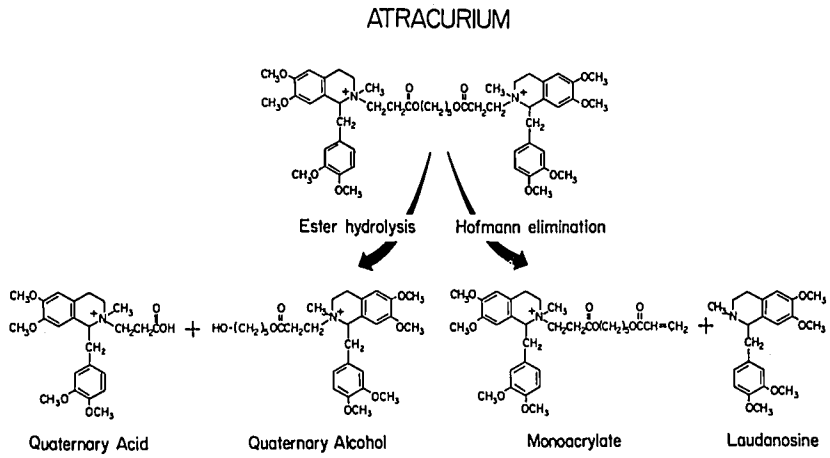


FIG. 2. Chemical formula for atracurium and its breakdown products that are formed from Hofmann elimination and ester hydrolysis.

method of constructing a dose–response curve produced essentially identical results.[21] However, for vecuronium and atracurium, the cumulative dose–response method produced larger $ED_{90}$ values than did the single-bolus method.[16,18,22] These shorter-acting drugs probably have larger $ED_{90}$ values when the cumulative method is used because much of the effect of the initial dose has dissipated before the last dose is given. Thus, the most accurate $ED_{90}$ for atracurium or vecuronium is that obtained with the single bolus method.

### Onset Time and Duration of Action

The onset time (time from administration of muscle relaxant to its peak effect) and duration of action (time from administration of muscle relaxant to 90% or 95% recovery of control twitch tension) are similar for both vecuronium and atracurium.[6–11,13–15,18–20,23–31] The doses of atracurium and vecuronium that depress twitch height less than 100% have onset times ranging from four to eight min. Because larger doses depress twitch tension 100%, onset time appears to be shorter. For example, four times the $ED_{95}$ of vecuronium has an onset time of 1.3 min[25]. When three times the $ED_{95}$ of atracurium was given, onset times were 1.2[14] and 1.3[19] min. Despite markedly increasing the dose, neither vecuronium nor atracurium has an onset time as short as that of succinylcholine.[32]

When equipotent doses are compared, both vecuronium and atracurium have a similar duration of action that is about one-third to one-half that of pancuronium.[6,8,10,11,13,15,18,19] For doses depressing twitch tension less than 100%, duration of action is about 15–30 min.[6,7,10,11,13,15,17,27,33] When three times the $ED_{95}$ of atracurium was given, duration of action was 76,[15] 73,[18] and 51[14] min. When an approximately equipotent dose of vecuronium was given, duration of action was 53[27] and 60[7] min. When a smaller dose of pancuronium (i.e., two times the $ED_{95}$) was given, the time from administration of muscle relaxant to only 25% recovery of control twitch tension was 158 min.[34]

Not surprisingly, recovery time (time from 25% to 75% recovery of control twitch tension) was also shorter (30–50%[6,8,11–13,35]) for vecuronium and atracurium than for pancuronium; these times ranged from 9 to 12 min for both atracurium and vecuronium.[6–8,10,11,15,20,27,35]

### Cumulative Effects

Both vecuronium and atracurium have little or no cumulative effects. The latter term often is confusing and misunderstood. Clinically, a lack of cumulative effect usually means that the duration of action of a given dose of neuromuscular blocking drug does not increase with repetitive doses. For example, Fahey *et al.*[6] administered a given dose of vecuronium to patients and observed its effect. When twitch tension had recovered to 25% of control, the same dose was given with the same resulting duration of action. The same duration of action from repetitive doses implies a lack of cumulative effects. Similar results were found by Buzello and Nöldge.[36] Ali *et al.*[37] observed a slight cumulative effect with vecuronium and no cumulative effect with atracurium.

Whether a neuromuscular blocking drug has a cumulative effect can be explained on a kinetic basis. With neuromuscular blockers that are not extensively metabolized (i.e., all blockers except succinylcholine and atracurium), recovery of neuromuscular function parallels the decrease in plasma concentration. Following a single dose of vecuronium or pancuronium, plasma concentration falls rapidly because of redistribution from the central to the peripheral compartment. With subsequent doses, muscle relaxant in the peripheral compartment limits this distribution phase, and the decrease in plasma concentration results from elimination or metabolism. Thus, both pancuronium, and to a lesser extent, vecuronium can be demonstrated to have cumulative effects. For atracurium, pharmacokinetic analyses reveal that there is not a distinct distribution phase with a rapid decrease in plasma concentration. Thus, recovery from the effects of atracurium depends predominantly upon elimination (in this case metabolism by Hofmann elimination and ester hydrolysis) rather than redistribution. As a result, recovery from the neuromuscular effects of atracurium is similar for the first and all subsequent doses.

### Pharmacokinetics

Both vecuronium and atracurium have distinct pharmacokinetic properties as compared with currently used nondepolarizing muscle relaxants. For example, unlike pancuronium, metocurine, *d*-tubocurarine, or gallamine, neither vecuronium nor atracurium depends heavily on the kidney for elimination. Only 10–25% of an injected dose of vecuronium is excreted in the urine,[38–40] the predominate route of elimination probably being the bile.[38] Although vecuronium should be metabolized into its 3-hydroxy, 17-hydroxy, and 3,17-hydroxy metabolites, as is pancuronium, only small amounts of these metabolites have been detected by methods such as thin-layer chromatography.[39] Although the precise extent to which vecuronium is metabolized has not been determined, apparently most of the drug excreted in the urine and bile is unchanged.[38] Further development of a sensitive assay distinguishing parent compound from its metabolites (e.g., mass spectrometry) may allow determination of the precise amount of vecuronium metabolized. How-

ever, these proposed metabolites have little or no cardiovascular or neuromuscular effects and, therefore, are of little concern.[41,42] In humans, vecuronium has a more rapid clearance (5.2 ± 0.7 ml·kg$^{-1}$·min$^{-1}$; mean ± SD) and a shorter elimination half-life (71 ± 20 min) than pancuronium (1.8 ± 0.4 ml·kg$^{-1}$·min$^{-1}$; 140 ± 25 min).[43] These two characteristics probably account for the shorter duration of action of vecuronium.

Because atracurium is metabolized completely through Hofmann elimination and ester hydrolysis, it should not be excreted either in the urine or bile except in the form of a metabolite. Although urinary and biliary excretion has not been determined in humans, elimination half-life is about 20–30 min.[44,45] Further confirmation of rapid metabolism is the rapid appearance of laudanosine in blood (*i.e.*, within 5–20 min).[44] Since laudanosine has no cardiovascular or neurologic effect when given in an iv dose of 4 mg·kg$^{-1}$, its known convulsant effect probably occurs at blood levels unlikely to be achieved by prolonged atracurium administration.[46] The dose (laudanosine)–response (convulsions) and blood levels of laudanosine required to produce convulsions has not been determined precisely. Furthermore, the extent to which laudanosine is formed with prolonged administration of atracurium has not been determined.

Even though atracurium and vecuronium produce neuromuscular blockade of similar duration, calculated values for their pharmacokinetic variables are quite different. For example, elimination half-life is about 22 min for atracurium and 71 min for vecuronium.[43,46]

The interrelationship between pharmacokinetic variables and neuromuscular blockade clearly differs for these drugs (fig. 3). All previous pharmacokinetic models, including that for vecuronium, assumed that elimination of a drug occurs from only one compartment. This approach is inappropriate for atracurium, because Hofmann elimination can occur from all body compartments. A pharmacokinetic model that accounts for multicompartmental elimination has not been developed.

## Factors that Influence the Pharmacokinetics or Pharmacodynamics of Vecuronium and Atracurium

### Anesthesia

Anesthetics enhance a nondepolarizing neuromuscular blockade in the following order: nitrous oxide–narcotics < halothane < isoflurane and enflurane.[47] The potencies of atracurium and vecuronium appear to be influenced less by the choice and concentration of anesthetic than are the potencies of *d*-tubocurarine and pancuronium. Enflurane and isoflurane augment a *d*-tubocurarine and pancuronium neuromuscular blockade about twice as much as does an equipotent concentration of

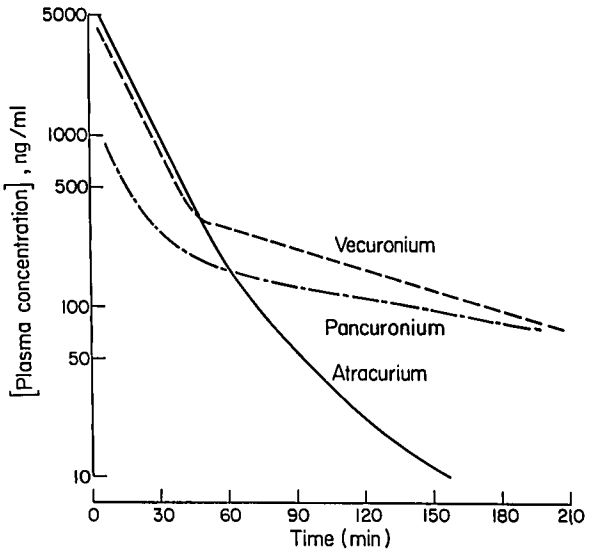


FIG. 3. Comparison of typical plasma decay curves from vecuronium, 0.28 mg/kg iv, pancuronium, 0.05 mg/kg, and atracurium, 0.5 mg/kg. Note that the peak plasma concentration of pancuronium is much lower because a smaller dose had been given (data taken from Fahey *et al.*[40,44]).

halothane[48–50] (fig. 4). For example, the $ED_{50}$s of *d*-tubocurarine and pancuronium are 1.70 and 0.27 mg/m$^2$, respectively, during isoflurane anesthesia and 5.60 and 0.49 mg/m$^2$, respectively, during halothane anesthesia.[49,50] In contrast, the augmentation of a vecuro-

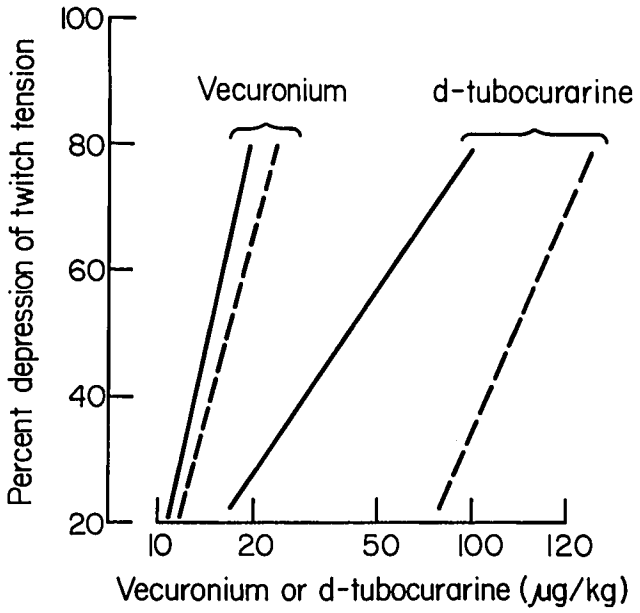


FIG. 4. Comparison of dose response curves of *d*-tubocurarine and vecuronium during isoflurane (——) and halothane (– – –) anesthesia (1.2 MAC concentration). Note that the difference between halothane and isoflurane is more with *d*-tubocurarine than it is with vecuronium (data taken from Miller *et al.*[49] and Rupp *et al.*[28]).

nium- or atracurium-induced neuromuscular blockade by enflurane and isoflurane is only 20–30% greater than the augmentation produced by halothane or nitrous oxide–narcotic anesthesia[17,26,28,51,52] (fig. 4).

Changes in the end-tidal concentration of inhaled anesthetics also have a lesser influence on neuromuscular blockades produced by vecuronium or atracurium than those produced by other nondepolarizing neuromuscular blockers. Increasing the anesthetic concentration from 1.2 MAC to 2.2 MAC decreases the $ED_{50}$ of vecuronium 51%, 33%, and 18% during enflurane, isoflurane, and halothane anesthesia, respectively.[28] Yet, the $ED_{50}$s of *d*-tubocurarine and pancuronium decreased 62% and 57%, respectively, for similar increases in the halothane concentration, and 30% and 70%, respectively, for similar increases in the isoflurane concentration.[54]

The reasons for vecuronium and atracurium being less influenced by the specific anesthetic and its dose or concentration are unknown.

## Age

*Infants and Children:* Comparing data from pediatric studies with those from adult studies sometimes is difficult because of differing experimental conditions and methods, such as depth of anesthesia, method of nerve stimulation, and method of constructing dose–response curves (single-bolus *vs.* cumulative). Despite these limitations, certain conclusions can be made cautiously.

The potency of both vecuronium and atracurium are similar in pediatric and adult patients. During halothane and nitrous oxide anesthesia, the $ED_{50}$ of vecuronium was 16.5 μg/kg in infants (<one year), 19.0 μg/kg for children (1–8 years), and 15.0 μg/kg for adults.[55] Goudsouzian *et al.*[56] found $ED_{50}$ values of 33 μg/kg and 23 μg/kg for children (2–9 years) and adolescents (10–17 years), respectively. The higher $ED_{50}$ values in the latter study may be partly explained by the use of the cumulative method for producing dose–response curves.[22] Although Brandom *et al.*[57] found a larger $ED_{50}$ value in children, the differences were small. Specifically, the $ED_{50}$ values were 85, 132, and 101 μg/kg for infants, children, and adolescents, respectively.[57,58] Goudsouzian *et al.*[59] found the $ED_{50}$ of atracurium to be 110 μg/kg for children and 120 μg/kg for adolescents. Interestingly, when Brandom *et al.*[57,58] recalculated their data on a surface-area basis, the $ED_{50}$ values were 1,600, 3,266, and 3,338 μg/m$^2$ for infants, children, and adolescents, respectively. This technique corrects for age-related changes in extracellular fluid volume (*i.e.*, the volume of distribution of neuromuscular blocking drugs). Thus, as is the case with *d*-tubocurarine, neuromuscular blockade may occur at a lower plasma concentration of atracurium in infants than in children and adolescents.[60]

The duration of a neuromuscular blockade induced by vecuronium (70 μg/kg) appears to be longer in infants (73 ± 27 min) than in children (35 ± 6 min) or adults (53 ± 7 min).[55] Goudsouzian *et al.*[56] did not study infants but found similar durations of action in children and adolescents. Conversely, the duration of atracurium's action is not prolonged in infants.[57,58,61] This difference between vecuronium and atracurium in infants may be related to the distinctive pharmacokinetic characteristics of each drug. With a larger volume of distribution in infants, more vecuronium (and *d*-tubocurarine[60]) would be in the peripheral compartment, inaccessible to the organs of clearance. Also, age-related changes in biliary clearance may account for vecuronium's longer duration of action in infants. For atracurium, the unusual pathways of elimination (Hofmann elimination and ester hydrolysis) result in its destruction in both the peripheral and central compartments. Thus, the duration of atracurium's action may depend less upon these age-related differences in organ function or volume of distribution.

*The Elderly:* d'Hollander *et al.*[62–64] found that a difference existed between vecuronium and atracurium in the elderly. Less vecuronium was required to sustain a steady state of paralysis, and recovery from neuromuscular blockade was longer in elderly patients (>60 years) than in younger patients,[62] yet, this same group found no age-related changes associated with atracurium.[64] This is the only study with atracurium in the elderly.

Rupp *et al.*[65] performed a pharmacokinetic and pharmacodynamic study with vecuronium in elderly patients (>70 years). The plasma concentration of vecuronium required to depress twitch height 50% did not change with age. Conversely, plasma clearance and the volume of distribution decreased in the elderly, probably because of decreased extracellular fluid and muscle mass. However, elimination half-life did not change in the elderly, suggesting that neuromuscular blockade should not be prolonged in the elderly. This contrasts with the results of d'Hollander *et al.*[62] Obviously, more study is required to better define the influence of age on the neuromuscular blockades produced by vecuronium and atracurium.

## Succinylcholine

Prior administration of succinylcholine probably enhances the neuromuscular blockades from vecuronium and atracurium.[11,53,66] However, as with pancuronium[67,68] and d-tubocurarine,[69,70] there is lack of agreement among various investigators. Stirt *et al.*[53] found that prior administration of succinylcholine, 1.0 mg/kg, increased the intensity of the atracurium neuromuscular blockade from 52% to 84% but did not increase its duration. d'Hollander *et al.*[71] found that succinylcholine augmented both the magnitude and duration of a vecuronium-induced neuromuscular blockade. This aug-

mentation would occur if vecuronium had been given within 30 min of succinylcholine administration. Krieg *et al.*[66] found that vecuronium given after succinylcholine caused a 19% greater depression of twitch tension than did vecuronium given without a prior dose of succinylcholine. Yet, Fisher and Miller[72] found that prior administration of succinylcholine did not alter a vecuronium-induced neuromuscular blockade. Clearly, the response to vecuronium, and probably atracurium, varies when given after succinylcholine.

### Acid–Base Balance

In cats, Funk *et al.*[73] found that acidosis augmented and alkalosis lessened a vecuronium-induced neuromuscular blockade. In humans, Gencarelli *et al.*[74] found that the timing of changes in end-tidal $P_{CO_2}$ was important as to its influence on vecuronium. During an end-tidal $P_{CO_2}$ of 25, 41, or 56 mmHg, neither the magnitude nor recovery time from a vecuronium-induced neuromuscular blockade changed. However, when vecuronium was infused at a constant rate and then the end-tidal $P_{CO_2}$ was changed, respiratory acidosis augmented and respiratory alkalosis lessened twitch tension. Thus, if respiratory acidosis occurs during a vecuronium-induced neuromuscular blockade, an augmented and prolonged blockade may result.

The influence of changes in acid–base balance on an atracurium-induced neuromuscular blockade has not been studied in humans. In an *in vivo* cat preparation, respiratory and metabolic acidosis augmented and respiratory and metabolic alkalosis lessened an atracurium neuromuscular blockade.[75]

## Cardiovascular Effects

The two major cardiovascular effects from older nondepolarizing blockers are tachycardia from vagal blockade (*e.g.*, pancuronium and gallamine) and hypotension from histamine release (*e.g.*, *d*-tubocurarine and metocurine). In contrast, vecuronium and, in large part, atracurium have little or no cardiovascular effects. For example, Booij *et al.*[76] gave three times the $ED_{90}$ of vecuronium iv to dogs and found no change in heart rate, blood pressure, and cardiac output. Marshall *et al.*[7] found that doses of vecuronium up to 20 times greater than those required for neuromuscular blockade produced no cardiovascular changes in cats and dogs. Furthermore, the proposed metabolites essentially were free of cardiovascular effects.[41] Lastly, vecuronium does not release histamine.[78]

Gregoretti *et al.*[79] administered vecuronium, 0.1 mg/kg iv, to patients anesthetized with enflurane and halothane. The only cardiovascular change was a slight decrease in heart rate (from 76 bpm to 63 bpm) during halothane anesthesia. However, the control heart rate was obtained before both vecuronium and halothane were administered. The investigators concluded that when vecuronium is used, its lack of vagolytic activity may allow drug- or reflex-induced bradycardia to occur more easily during surgery and anesthesia. Yet, Engbaek *et al.*[80] found no change in heart rate, arterial blood pressures, or systolic time intervals from vecuronium, 57 μg/kg iv, in patients also anesthetized with halothane. To severely test vecuronium's apparent lack of cardiovascular effects, Morris *et al.*[81] gave 0.28 mg/kg (12 times the $ED_{90}$) of vecuronium iv to patients anesthetized with halothane who were about to undergo coronary artery bypass grafting. Heart rate and arterial blood pressure did not change. Cardiac output decreased 9% and systemic vascular resistance decreased 12%.

Atracurium does cause release of histamine but in amounts less than those produced by metocurine or *d*-tubocurarine.[82] Accordingly, when doses of atracurium up to 0.4 mg/kg iv were given, no significant change (<5% of control) in arterial blood pressure or heart rate occurred during various anesthetic techniques.[17–20,83] Occasionally these doses were associated with flushing.[58,59] Larger doses of atracurium ranging from 0.5 mg/kg to 1.0 mg/kg have been associated with a typical histamine-like cardiovascular response, including hypotension and tachycardia. For example, Basta *et al.*[15] noted that arterial blood pressure decreased 13% and 20% from control after administration of atracurium, 0.5 mg/kg and 0.6 mg/kg iv. Heart rate increased to 105% and 108% of control, respectively. These changes were associated with slight facial flushing. Pokar and Brandt[84] administered atracurium, 0.6–1.0 mg/kg, into right atrial catheters in patients who had undergone coronary artery bypass surgery. Four of nine patients had a decrease of more than 10% (maximum 17%) in arterial blood pressure. We conclude that doses less than 0.6 mg/kg rarely are associated with cardiovascular changes. Larger doses can cause a transient histamine response, but less than that associated with *d*-tubocurarine or metocurine.

## Antagonism

There have been no reports of difficulty in antagonizing either a vecuronium- or atracurium-induced neuromuscular blockade with anticholinesterase drugs. Basta *et al.*[15] found that the doses of neostigmine required to antagonize neuromuscular blockade produced by atracurium and metocurine were similar. Also, the times from administration of neostigmine to recovery of 98% control twitch height were similar: 8.2 min for atracurium and 7.6 min for metocurine. Conversely, Fahey *et al.*[6] found that less neostigmine was required to antagonize a neuromuscular blockade induced by vecuronium

than one induced by pancuronium. However, this conclusion was based on data obtained from administration of intermittent boluses of neostigmine. Possibly because a neuromuscular blockade by vecuronium would terminate spontaneously more rapidly than one by pancuronium, less neostigmine would be required with vecuronium. To compensate for the possibility that this pharmacokinetic characteristic would lessen the neostigmine requirement, Gencarelli and Miller[85] continuously infused either pancuronium or vecuronium and found no difference in the neostigmine dose required for antagonism. They concluded that vecuronium and pancuronium effectively and equally (independent of their pharmacokinetics) are antagonized by neostigmine. Baird *et al.*[86] found that edrophonium, 0.5–1.0 mg/kg iv, rapidly (*i.e.*, 1–2 min) restored a vecuronium depressed twitch to 80% (*i.e.*, 20% depression of twitch tension still remaining) of the control height but that an additional 6 to 8 minutes was required for complete restoration of neuromuscular function, as judged by the train-of-four response.

These studies indicate that both vecuronium- and atracurium-induced neuromuscular blockades are antagonized readily by endrophonium and neostigmine. Because the new neuromuscular blocking drugs produce a blockade of relatively short duration, an antagonist may not be necessary. For example, Katz *et al.*[18] found it necessary to antagonize only five of 25 neuromuscular blockades from atracurium. Undoubtedly, administration of an antagonist is not always necessary. However, we believe spontaneous recovery should not be relied upon for termination of neuromuscular blockade unless a sustained response to a tetanic stimulus of 100 Hz for 5 s or a completely normal train-of-four unquestionably exists.

## Special Clinical Situations

### Cardiac Surgery and Cardiopulmonary Bypass

Because they have little or no cardiovascular effects, vecuronium and atracurium may be appropriate neuromuscular blocking drugs for cardiac surgery.[81,84,87] Very large doses of vecuronium (*e.g.*, 0.28 mg/kg) can be given with no cardiovascular effects. However, large doses of atracurium may cause hypotension.[84] For example, when atracurium, 0.3 mg/kg, was given to eight patients about to undergo elective coronary artery surgery, one patient had a decrease in mean arterial pressure (from 70 to 55 mmHg) and other signs consistent with histamine release.[87] Perhaps prior diuretic therapy made these patients more susceptible to even the slight histamine release associated with atracurium administration.

The lack of cardiovascular effects associated with large doses of vecuronium can be a disadvantage when the high-dose fentanyl approach to anesthesia is used. Pancuronium is commonly used: its vagolytic effect counteracts the tendency of fentanyl to produce bradycardia. Thus, when vecuronium is given with high-dose fentanyl anesthesia (especially cardiac anesthesia) heart rate often decreases.[88]

Hypothermia and cardiopulmonary bypass also can affect the amount of atracurium or vecuronium required for neuromuscular blockade. Flynn *et al.*[89] found that 43% less atracurium was required to maintain a 90–95% neuromuscular blockade during hypothermic cardiopulmonary bypass. They attributed the apparent increased potency of atracurium to the fact that hypothermia reduced the rate of Hofmann degradation. Buzello *et al.*[90] compared pancuronium and vecuronium before and after cardiopulmonary bypass. Before bypass pancuronium acted about two times longer than vecuronium. However, during hypothermic bypass, the durations of action of pancuronium and vecuronium increased 1.8-fold and fivefold, respectively. Thus, during hypothermic bypass, pancuronium and vecuronium had similar durations of action. Consequently, we conclude that hypothermic cardiopulmonary bypass is associated with a marked increase in the duration of neuromuscular blockade from both atracurium and vecuronium.

### Obstetrics

Both vecuronium and atracurium have been successfully used in patients undergoing cesarean section. Baraka *et al.*[91] gave vecuronium, 0.05 mg/kg, to patients undergoing cesarean section after recovery from an initial dose of succinylcholine had occurred. The mean duration of neuromuscular blockade was 19 min. Furthermore, Apgar scores did not differ for infants delivered before vecuronium administration (n = 9) and those delivered after vecuronium administration (n = 19). Dailey *et al.*[92] confirmed that vecuronium had difficulty crossing the placental barrier. Specifically, when a 0.04 mg/kg dose of vecuronium or pancuronium was given to the mother, 8.5–26.4 ng/ml and 12.2–34.2 ng/ml, respectively, of drug was found in umbilical-cord venous blood. The ratio of the drug concentration in umbilical-cord venous blood to that in maternal venous blood was 0.11 for vecuronium and 0.19 for pancuronium. In a similar study, Demetriou *et al.*[93] also found a ratio of 0.11 for vecuronium. Lastly, plasma clearance of vecuronium is more rapid in pregnant patients, probably because of cardiovascular and fluid shifts during pregnancy.[92] Although the increased clearance rate during pregnancy would presumably result in a shorter neuromuscular blockade, this assumption has not been verified.

Frank *et al.*[94] also successfully used atracurium in patients undergoing cesarean section. In five of 26 patients, atracurium levels in maternal blood ranged from 0.7 μg/ml to 3.3 μg/ml 3 min after drug administration. Concentrations in umbilical-cord venous blood

were too small to detect (<0.23 μg/ml). Perhaps a more sensitive assay similar to that of Fahey *et al.*[44] (sensitivity to 10 ng/ml) would have been able to detect atracurium in such samples. Still, there is no reason to believe that highly ionized drugs such as vecuronium or atracurium would cross the placental barrier in significant amounts.

### Renal Disease

Because neither vecuronium nor atracurium depend heavily on the kidney for their elimination, duration of neuromuscular blockade should not be prolonged in patients with renal failure. This conclusion indeed has been confirmed with large doses of atracurium (0.5–2.3 mg/kg)[44,95] and vecuronium (0.28 mg/kg).[40] Thus, vecuronium and atracurium are the only two currently used, nondepolarizing blocking drugs whose neuromuscular blockades are not prolonged by renal failure.

### Liver Disease

Because atracurium is metabolized through Hofmann elimination and ester hydrolysis, its pharmacokinetics and duration of neuromuscular blockade should not be altered by impaired hepatic function. Ward and Neill[96] determined the pharmacokinetics of atracurium in normal patients and in six patients with acute hepatic and renal failure. The values for pharmacokinetic variables did not differ for the two groups, plasma elimination half-life being 22 min for patients with hepatic and renal failure and 21 min for normal patients. Although duration of neuromuscular blockade was not measured, it presumably was not prolonged by hepatic failure.

Because vecuronium significantly is eliminated in the bile, one might predict that liver disease would prolong a vecuronium-induced neuromuscular blockade. After vecuronium, 0.2 mg/kg iv, was given to patients with cirrhosis, elimination half-life increased from 58 min to 84 min, and plasma clearance decreased 50%.** Also, the duration of neuromuscular blockade increased from 62 min to 130 min.** However, protein binding of vecuronium was not altered by the presence of cirrhosis.[97]

We conclude that the duration of neuromuscular blockade produced by vecuronium, but *not* atracurium, will be increased in patients with impaired hepatic function.

## Summary

Vecuronium and atracurium provide additional flexibility to the clinician using neuromuscular blocking drugs. The shorter duration of action, lack of significant cardiovascular effects, and the lack of dependence on the kidney for elimination provide clinical advantages over, or alternatives to, currently available nondepolarizing neuromuscular blocking drugs.

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## References

1. Hilgenberg JC: Comparison of the pharmacology of vecuronium and atracurium with that of other currently available muscle relaxants. Anesth Analg 62:524–531, 1983
2. Bowman WC: New neuromuscular blocking drugs in anesthetic practice. Pharmacy Int 4:131–134, 1983
3. Savage DS, Sleigh T, Carlyle I: The emergence of Org NC 45, 1-[(2β,3α,5α,16β,17β)-3,17-bis(acetyloxy)-2-(1-piperidinyl)-androstan-16-yl]-1-methylpiperidinium bromide, from the pancuronium series. Br J Anaesth 52(Suppl 1):3S–9S, 1980
4. Stenlake JB, Waigh RD, Urwin J, Dewar GH, Coker GG: Atracurium: Conception and inception. Br J Anaesth 55(Suppl 1):3S–10S, 1983
5. Chapple DJ, Clark JS: Pharmacological action of breakdown products of atracurium and related substances. Br J Anaesth 55(Suppl 1):11S–15S, 1983
6. Fahey MR, Morris RB, Miller RD, Sohn YJ, Cronnelly R, Gencarelli P: Clinical pharmacology of ORG NC45 (Norcuron™): A new nondepolarizing muscle relaxant. ANESTHESIOLOGY 55:6–11, 1981
7. Agoston S, Salt P, Newton D, Bencini A, Boomsma P, Erdmann W: The neuromuscular blocking action of Org NC 45, a new pancuronium derivative, in anaesthetized patients. A pilot study. Br J Anaesth 52(Suppl 1):53S–59S, 1980
8. Crul JF, Booij LHDJ: First clinical experiences with Org NC 45. Br J Anaesth 52(Suppl 1):49S–52S, 1980
9. Baird WLM, Herd D: A new neuromuscular blocking drug, Org NC 45. A pilot study in man. Br J Anaesth 52(Suppl 1):61S–62S, 1980
10. Buzello W, Bischoff G, Kuhls E, Nöldge G: The new nondepolarizing muscle relaxant Org NC 45 in clinical anaesthesia: Preliminary results. Br J Anaesth 52(Suppl 1):62S–64S, 1980
11. Krieg N, Crul JF, Booij LHDJ: Relative potency of Org NC 45, pancuronium, alcuronium and tubocurarine in anaesthetized man. Br J Anaesth 52:783–788, 1980
12. Walts LF, Stirt JA, Katz RL: A comparison of neuromuscular blocking effects of norcuron and pancuronium. ANESTHESIOLOGY 55:A210, 1981
13. Gramstad L, Lilleaasen P, Minsaas B: Comparative study of atracurium, vecuronium (Org NC 45) and pancuronium. Br J Anaesth 55(Suppl 1):95S–96S, 1983
14. Payne JP, Hughes R: Evaluation of atracurium in anaesthetized man. Br J Anaesth 53:45–54, 1981.
15. Basta SJ, Ali HH, Savarese JJ, Sunder N, Gionfriddo M, Cloutier G, Lineberry C, Cato AE: Clinical pharmacology of atracurium besylate (BW 33A): A new non-depolarizing muscle relaxant. Anesth Analg 61:723–729, 1982
16. Nagashima H, Yun H, Radnay PA, Duncalf D, Kaplan R, Foldes FF: Influence of anesthesia on human dose–response of Org-NC45. ANESTHESIOLOGY 55:A202, 1981
17. Rupp SM, Fahey MR, Miller RD: Neuromuscular and cardiovascular effects of atracurium during nitrous oxide–fentanyl and nitrous oxide–isoflurane anaesthesia. Br J Anaesth 55(Suppl 1):67S–70S, 1983
18. Katz RL, Stirt J, Murray AL, Lee C: Neuromuscular effects of atracurium in man. Anesth Analg 61:730–734, 1982

** Lebrault C, Berger JL, d'Hollander AA, Gomeni R, Henzel D, Duvaldestin P: Pharmacokinetics and pharmacodynamics of vecuronium (ORG NC45) in patients with cirrhosis. (Unpublished data)

19. Savarese JJ, Basta SJ, Ali HH, Sunder N, Moss J: Neuromuscular and cardiovascular effects of BW 33A (atracurium) in patients under halothane anesthesia. ANESTHESIOLOGY 57:A262, 1982
20. Sokoll MD, Gergis SD, Mehta M, Ali NM, Lineberry C: Safety and efficacy of atracurium (BW33A) in surgical patients receiving balanced or isoflurane anesthesia. ANESTHESIOLOGY 58:450–455, 1983
21. Donlon JV Jr, Savarese JJ, Ali HH, Teplik RS: Human dose–response curves for neuromuscular blocking drugs: A comparison of two methods of construction and analysis. ANESTHSIOLOGY 53:161–166, 1980
22. Fisher DM, Fahey MR, Cronnelly R, Miller RD: Potency determination for vecuronium (ORG NC45): Comparison of cumulative and single-dose techniques. ANESTHESIOLOGY 57: 309–310, 1982
23. Ørding H, Viby Mogensen J: Dose–response curves for OR NC 45 [sic] and pancuronium. Acta Anaesthesiol Scand 25(Suppl 72):73, 1981
24. Swen J: Org NC 45: Initial experiences. Br J Anaesth 52(Suppl 1):66S–67S, 1980
25. Viby–Mogensen J, Jørgensen BC, Engbaek J, Sørensen B: On Org NC 45 and halothane anaesthesia. Preliminary results. Br J Anaesth 52(Suppl 1):67S–69S, 1980
26. Duncalf D, Nagashima H, Hollinger I, Badola RP, Kaplan R, Foldes FF: Relaxation with Org-NC45 during enflurane anesthesia. ANESTHESIOLOGY 55:A203, 1981
27. Fragen RJ, Robertson EN, Booij LHDJ, Crul JF: A comparison of vecuronium and atracurium in man. ANESTHESIOLOGY 57:A253, 1982
28. Rupp SM, Miller RD, Gencarelli PJ: Vecuronium-induced neuromuscular blockade during enflurane, halothane and isoflurane in humans. ANESTHESIOLOGY 60:102–105, 1984
29. Nguyen HD, Nagashima H, Kaplan R, Lauber R, Yun H, Foldes FF: Relaxation with BW33A under neurolept and enflurane anesthesia. ANESTHESIOLOGY 57:A277, 1982
30. Ramsey FM, White PA, Stullken EH, Allen LL, Roy RC: Enflurane potentiation of neuromuscular blockade by atracurium. ANESTHESIOLOGY 57:A255, 1982
31. Foldes FF, Nagashima H, Boros M, Tassonyi E, Fitzal S, Agoston S: Muscular relaxation with atracurium, vecuronium and Duador under balanced anaesthesia. Br J Anaesth 55(Suppl 1):97S–103S, 1983
32. Scott RPF, Goat VA: Atracurium: Its speed of onset. A comparison with suxamethonium. Br J Anaesth 54:909–911, 1982
33. Stirt JA, Murray AL, Katz RL, Schehl DL, Lee C: Atracurium during halothane anesthesia in humans. Anesth Analg 62:207–210, 1983
34. Lebowitz PW, Ramsey FM, Savarese JJ, Ali HH, deBros FM: Combination of pancuronium and metocurine: Neuromuscular and hemodynamic advantages over pancuronium alone. Anesth Analg 60:12–17, 1981
35. Bencini A, Agoston S, Ket J: Use of the human "isolated arm" preparation to indicate qualitative aspects of a new neuromuscular blocking agent, Org NC 45. Br J Anaesth 52(Suppl 1):43S–47S, 1980
36. Buzello W, Nöldge G: Repetitive administration of pancuronium and vecuronium (Org NC 45, Norcuron) in patients undergoing long lasting operations. Br J Anaesth 54:1151–1157, 1982
37. Ali HH, Savarese JJ, Basta SJ, Sunder N, Gionfriddo M: Evaluation of cumulative properties of three new non-depolarizing neuromuscular blocking drugs BW A444U, atracurium and vecuronium. Br J Anaesth 55(Suppl 1):107S–111S, 1983
38. Upton RA, Nguyen T-L, Miller RD, Castagnoli N Jr: Renal and biliary elimination of vecuronium (ORG NC 45) and pancuronium in rats. Anesth Analg 61:313–316, 1982
39. Sohn YJ, Bencini A, Scaf AHJ, Kersten UW, Gregoretti S, Agoston S: Pharmacokinetics of vecuronium in man. ANESTHESIOLOGY 57:A256, 1982
40. Fahey MR, Morris RB, Miller RD, Nguyen T-L, Upton RA: Pharmacokinetics of Org NC45 (Norcuron) in patients with and without renal failure. Br J Anaesth 53:1049–1053, 1981
41. Marshall IG, Gibb AJ, Durant NN: Neuromuscular and vagal blocking actions of pancuronium bromide, its metabolites, and vecuronium bromide (Org NC 45) and its potential metabolites in the anaesthetized cat. Br J Anaesth 55:703–714, 1983
42. Booij LHDJ, Vree TB, Hurkmans F, Reekers-Ketting JJ, Crul JF: Pharmacokinetics and pharmacodynamics of the muscle relaxant drug Org NC-45 and each of its hydroxy metabolites in dogs. Anaesthesist 30:329–333, 1982
43. Cronnelly R, Fisher DM, Miller RD, Gencarelli P, Nguyen-Gruenke L, Castagnoli N Jr: Pharmacokinetics and pharmacodynamics of vecuronium (ORG NC45) and pancuronium in anesthetized humans. ANESTHESIOLOGY 58:405–408, 1983
44. Fahey MR, Rupp SM, Fisher DM, Miller RD, Sharma M, Canfell C, Castagnoli K, Hennis PJ: The pharmacokinetics and pharmacodynamics of atracurium in patients with and without renal failure. ANESTHESIOLOGY (in press)
45. Ward S, Neill EAM, Weatherley BC, Corall IM: Pharmacokinetics of atracurium besylate in healthy patients (after a single i.v.) bolus dose. Br J Anaesth 55(Suppl 1):113–118, 1983
46. Mercier J, Mercier E: Action de quelques alcaloïdes secondaires de l'opium sur l'électrocorticogramme du chien. C R Soc Biol 149:760–762, 1955
47. Miller RD, Savarese JJ: Pharmacology of muscle relaxants, their antagonists, and monitoring of neuromuscular function, Anesthesia. Volume 1. Edited by Miller RD. New York, Churchill Livingstone, 1981, pp 487–538
48. Fogdall RP, Miller RD: Neuromuscular effects of enflurane, alone and combined with *d*-tubocurarine, pancuronium, and succinylcholine, in man. ANESTHESIOLOGY 42:173–178, 1975
49. Miller RD, Eger EI II, Way WL, Stevens WC, Dolan WM: Comparative neuromuscular effects of Forane and halothane alone and in combination with *d*-tubocurarine in man. ANESTHESIOLOGY 35:38–42, 1971
50. Miller RD, Way WL, Dolan WM, Stevens WC, Eger EI II: Comparative neuromuscular effects of pancuronium, gallamine, and succinylcholine during Forane and halothane anesthesia in man. ANESTHESIOLOGY 35:509–514, 1971
51. Ramsey FM, White PA, Stullken EH, Allen LL, Roy RC: Enflurane potentiation of neuromuscular blockade by atracurium. ANESTHESIOLOGY 57:A255, 1982
52. Foldes FF, Bencini A, Newton D: Influence of halothane and enflurane on the neuromuscular effects of Org NC 45 in man. Br J Anaesth 52(Suppl 1):64S–65S, 1980
53. Stirt JA, Katz RL, Murray AL, Schehl DL, Lee C: Modification of atracurium blockade by halothane and by suxamethonium. A review of clinical experience. Br J Anaesth 55(Suppl 1):71S–75S, 1983
54. Miller RD, Way WL, Dolan WM, Stevens WC, Eger EI II: The dependence of pancuronium- and *d*-tubocurarine-induced neuromuscular blockades on alveolar concentrations of halothane and Forane. ANESTHESIOLOGY 37:573–581, 1972
55. Fisher DM, Miller RD: Neuromuscular effects of vecuronium (ORG NC45) in infants and children during $N_2O$, halothane anesthesia. ANESTHESIOLOGY 58:519–523, 1983
56. Goudsouzian NG, Martyn JJA, Liu LMP, Gionfriddo M: Safety and efficacy of vecuronium in adolescents and children. Anesth Analg 62:1083–1088, 1983
57. Brandom BW, Rudd GD, Cook DR: Clinical pharmacology of atracurium in paediatric patients. Br J Anaesth 55(Suppl 1):117S–121S, 1983
58. Brandom BW, Woelfel SK, Cook DR, Fehr BL, Rudd GD:

Clinical pharmacology of atracurium in infants. Anesth Analg (In press)
59. Goudsouzian NG, Liu LMP, Cote CJ, Gionfriddo M, Rudd GD: Safety and efficacy of atracurium in adolescents and children anesthetized with halothane. ANESTHESIOLOGY 59:459–462, 1983
60. Fisher DM, O'Keeffe C, Stanski DR, Cronnelly R, Miller RD, Gregory GA: Pharmacokinetics and pharmacodynamics of d-tubocurarine in infants, children, and adults. ANESTHESIOLOGY 57:203–208, 1982
61. Nightingale DA, Bush GH: Atracurium in paediatric anaesthesia. Br J Anaesth 55(Suppl 1):115S, 1983
62. d'Hollander A, Massaux F, Nevelsteen M, Agoston S: Age-dependent dose-response relationship of Org NC 45 in anaesthetized patients. Br J Anaesth 54:653–657, 1982
63. d'Hollander AA, Nevelsteen M, Barvais L, Baurain M: Effect of age on the establishment of muscle paralysis induced in anaesthetized adult subjects by ORG NC45. Acta Anaesthesiol Scand 27:108–110, 1983
64. d'Hollander AA, Luyckx C, Barvais L, De Ville A: Clinical evaluation of atracurium besylate requirement for a stable muscle relaxation during surgery: Lack of age-related effects. ANESTHESIOLOGY 59:237–240, 1983
65. Rupp SM, Fisher DM, Miller RD, Castagnoli K: Pharmacokinetics and pharmacodynamics of vecuronium in the elderly. ANESTHESIOLOGY 59:A270, 1983
66. Krieg N, Hendricks HHL, Crul JF: Influence of suxamethonium on the potency of Org NC 45 in anaesthetized patients. Br J Anaesth 53:259–262, 1981
67. Katz RL: Modification of the action of pancuronium by succinylcholine and halothane. ANESTHESIOLOGY 35:602–606, 1971
68. Waltz LF, Rusin WD: The influence of succinylcholine on the duration of pancuronium neuromuscular blockade. Anesth Analg 56:22–25, 1977
69. Katz RL, Norman J, Seed RF, Conrad L: A comparison of the effects of suxamethonium and tubocurarine in patients in London and New York. Br J Anaesth 41:1041–1047, 1969
70. Walts LF, Dillon JB: Clinical studies of the interaction between D-tubocurarine and succinylcholine. ANESTHESIOLOGY 31:39–44, 1969
71. d'Hollander AA, Agoston S, De Ville A, Cuvelier F: Clinical and pharmacological actions of a bolus injection of suxamethonium: Two phenomena of distinct duration. Br J Anaesth 55:131–134, 1983
72. Fisher DM, Miller RD: Interaction of succinylcholine and vecuronium during $N_2O$-halothane anesthesia. ANESTHESIOLOGY 59:A278, 1983
73. Funk DI, Crul JF, van der Pol FM: Effects of changes in acid–base balance on neuromuscular blockade produced by ORG-NC 45. Acta Anaesthesiol Scand 24:119–124, 1980
74. Gencarelli PJ, Swen J, Koot HWJ, Miller RD: The effects of hypercarbia and hypocarbia on pancuronium and vecuronium neuromuscular blockades in anesthetized humans. ANESTHESIOLOGY 59:376–380, 1983
75. Hughes R, Chapple DJ: The pharmacology of atracurium: A new competitive neuromuscular blocking agent. Br J Anaesth 53:31–44, 1981
76. Booij LHDJ, Edwards RP, Sohn YJ, Miller RD: Cardiovascular and neuromuscular effects of Org NC 45, pancuronium, metocurine, and *d*-tubocurarine in dogs. Anesth Analg 59:26–30, 1980
77. Marshall RJ, McGrath JC, Miller RD, Docherty JR, Lamar J-C: Comparison of the cardiovascular actions of Org NC 45 with those produced by other non-depolarizing neuromuscular blocking agents in experimental animals. Br J Anaesth 52(Suppl 1):21S–32S, 1980
78. Basta SJ, Saverese JJ, Ali HH, Sunder N, Moss J, Gionfriddo M, Embree P: Vecuronium does not alter serum histamine within the clinical dose range. ANESTHESIOLOGY 59:A273, 1983
79. Gregoretti SM, Sohn YJ, Sai RL: Heart rate and blood pressure changes after ORG NC45 (vecuronium) and pancuronium during halothane and enflurane anesthesia. ANESTHESIOLOGY 56:392–395, 1982
80. Engbaek J, Ørding H, Sørensen B, Viby-Mogensen J: Cardiac effects of vecuronium and pancuronium during halothane anaesthesia. Br J Anaesth 55:501–505, 1983
81. Morris RB, Cahalan MK, Miller RD, Wilkinson PL, Quasha AL, Robsinson SL: The cardiovascular effects of vecuronium (ORG NC45) and pancuronium in patients undergoing coronary artery bypass grafting. ANESTHESIOLOGY 58:438–440, 1983
82. Basta SJ, Savarese JJ, Ali HH, Moss J, Gionfriddo M: Histamine-releasing potencies of atracurium besylate (BW 33A), metocurine, and *D*-tubocurarine. ANESTHESIOLOGY 57:A261, 1982
83. Hilgenberg JC, Stoelting RK, Harris WA: Haemodynamic effects of atracurium during enflurane–nitrous oxide anaesthesia. Br J Anaesth 55(Suppl 1):81S, 1983
84. Pokar H, Brandt L: Haemodynamic effects of atracurium in patients after cardiac surgery. Br J Anaesth 55(Suppl 1):139S, 1983
85. Gencarelli PJ, Miller RD: Antagonism of Org NC45 (vecuronium) and pancuronium neuromuscular blockade by neostigmine. Br J Anaesth 54:53–56, 1982
86. Baird WLM, Bowman WC, Kerr WJ: Some actions of Org NC 45 and of edrophonium in the anaesthetized cat and in man. Br J Anaesth 54:375–385, 1982
87. Philbin DM, Machaj VR, Tomichek RC, Schneider RC, Alban JC, Lowenstein E, Lineberry CC: Haemodynamic effects of bolus injections of atracurium in patients with coronary artery disease. Br J Anaesth 55(Suppl 1):131S–134S, 1983
88. Salmenperä M, Peltola K, Takkunen O, Heinonen J: Cardiovascular effects of pancuronium and vecuronium during high-dose fentanyl anesthesia. Anesth Analg 62:1059–1064, 1983
89. Flynn PJ, Hughes R, Walton B: The use of atracurium in cardiopulmonary bypass with induced hypothermia. ANESTHESIOLOGY 59:A262, 1983
90. Buzello W, Schluermann D, Schindler M, Spillner F: Hypothermic cardiopulmonary bypass and neuromuscular blockade by pancuronium and vecuronium. ANESTHESIOLOGY (In press)
91. Baraka A, Noueihed R, Sinno H, Wakid N, Agoston S: Succinylcholine–vecuronium (Org NC 45) sequence for cesarean section. Anesth Analg 62:909–913, 1983
92. Dailey PA, Fisher DM, Shnider SM, Baysinger CL, Shinohara Y, Miller RD, Abboud TK, Kim KC: Pharmacokinetics, placental transfer, and neonatal effects of vecuronium and pancuronium administered during cesarean section. ANESTHESIOLOGY 60:569–574, 1984
93. Demetriou M, Depoix J-P, Diakite B, Fromentin M, Duvaldestin P: Placental transfer of Org NC 45 in women undergoing caesarean section. Br J Anaesth 54:643–645, 1982
94. Frank M, Flynn PJ, Hughes R: Atracurium in obstetric anaesthesia. A preliminary report. Br J Anaesth 55(Suppl 1):113S–114S, 1983
95. Hunter JM, Jones RS, Utting JE: Use of atracurium in patients with no renal function. Br J Anaesth 54:1251–1258, 1982
96. Ward S, Neill EAM: Pharmacokinetics of atracurium in acute hepatic failure (with acute renal failure). Br J Anaesth 55:1169–1172, 1983
97. Duvaldestin P, Henzel D: Binding of tubocurarine, fazadinium, pancuronium and Org NC 45 to serum proteins in normal man and in patients with cirrhosis. Br J Anaesth 54:513–516, 1982