SUCCINYLCHOLINE IN CARDIOVASCULAR SURGERY OF INFANTS AND CHILDREN

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RECENT published reports describing several anesthetic techniques for cardiac surgery have recommended that light planes of general anesthesia be employed (1–3). Although there has been no systematic comparison of anesthetic agents or techniques to support this recommendation, the clinical experience behind it has been large. Patients who were considered prohibitive anesthetic and surgical risks a few years ago have successfully undergone surgery for correction of their cardiac disease as a result, in part, of such anesthetic techniques. Most of this reported experience has been accumulated in the treatment of adults with acquired heart disease. There is a remarkable paucity of information concerning anesthetic techniques for surgery of congenital heart disease, despite its twenty-year history (4–6).

Light general anesthesia for cardiac surgery has been made possible by three innovations in anesthesia techniques: the use of curare-like drugs, the use of hyperventilation with controlled respiration, and the use of analgesic concentrations of general anesthetic agents. In the absence of much precedence we have devised and successfully used an anesthetic technique for infants and children which incorporated these innovations. This technique, which uses succinylcholine with analgesic levels of ether and controlled respiration, allows ideal operating conditions for the surgeon even in the smallest patients with minimal cardiac effects of anesthetic agents. Data which we have collected indicate that children are more resistant than adults to the effects of succinylcholine, confirming the original observation of Stead (7). Succinylcholine can therefore be used with greater safety in infants and children. The purpose of this report is to describe this anesthetic technique, to present the results of its use in 150 patients, and to present data on the relative resistance of infants and children to the effects of succinylcholine.

ANESTHETIC TECHNIQUE

To prevent dehydration, small children were allowed liquids up to four hours before surgery. In older children this period was extended. In order that light levels of general anesthesia could be used, both infants and children were generously premedicated. Drugs were prescribed on a weight basis. The following drugs and average doses were used: pentobarbital sodium, 2 mg. per pound by mouth, or 3 to 4 mg.

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per pound by rectum; chloral hydrate, 25 mg. per pound by rectum; intramuscular meperidine, 1 mg. per pound of body weight less ten pounds; and intramuscular scopolamine or atropine, 0.1 mg. per 20 pounds of body weight. Pentobarbital or chloral hydrate was given three hours preoperatively. Meperidine and scopolamine were given one hour preoperatively. Most children arrived at the operating room asleep but able to respond to the stimulus of being moved or manipulated without crying or excitement.

Fifty per cent or less cyclopropane with oxygen was used for induction, which required less than one minute. Because of its potency, the use of cyclopropane avoided the breath-holding, respiratory obstruction, and hypoxia often associated with open drop techniques. This was important since many of these patients were already hypoxic as a result of their heart disease. Induction was accomplished with a to-and-fro absorption system selected in size according to the patient's size. A semiclosed technique was used with a gas flow of 1,500 to 3,000 cc. per minute. Originally children were intubated under deep cyclopropane anesthesia. This procedure was so often associated with alarming bradycardia and at times with nodal cardiac rhythm that it was abandoned, and the procedure was adopted of maintaining light anesthesia with cyclopropane until an infusion is started by cutdown. A single dose of succinylcholine (10–30 mg.) was then given intravenously to facilitate intubation. We have occasionally noted a transient bradycardia without hypotension lasting less than fifteen seconds when single doses of succinylcholine were injected rapidly. These have been of no consequence even with gross overdosage (for example, 4 mg./kg.) except that the duration of apnea was proportional to the dose. The use of succinylcholine for intubation also allowed the insertion of the largest possible bore endotracheal tube into the trachea. This was important when an insufflation system was to be used for controlled respiration. The pharynx and cords were sprayed with 4 per cent cocaine, and the endotracheal tube was lubricated with a topical anesthetic lubricant. Following intubation children weighing less than 35 pounds were ventilated through an Ayre T-piece insufflation system (8). In children from 40 to 80 pounds a to-and-fro absorption system was used. A circle absorption system was used in children over 80 pounds. Following intubation ether-oxygen was begun and the percentage of cyclopropane in the mixture was gradually reduced over a period of five minutes. An 0.2 per cent solution of succinylcholine in 5 per cent dextrose in water was started intravenously when respiration returns. Apnea was again produced, and thereafter succinylcholine was used intermittently in sufficient dose to maintain apnea. The periodic return of diaphragmatic contractions was used as a check against overdosage. Respiration was controlled with light ether anesthesia from the beginning of operation until the start of closure of the chest. Ventilation was maintained at the maximum rate and depth which will not interfere with the surgical procedure. Continuous apnea permitted an absolutely quiet mediastinum and diaphragm much appreciated by the surgeon. Within ten minutes from cessation of the succinylcholine drip, respiratory activity returned and by the time the operation was completed (or before) children were moving, breathing spontaneously and adequately. If necessary 50 per cent nitrous oxide with oxygen was administered for closure of the chest.

Early in the development of this technique several monitoring devices were used routinely. These included electrocardiogram, ear oximeter, and intra-arterial blood pressure recordings. With experience it was found that these monitoring devices with the exception of the electrocardiogram were not necessary when careful attention was paid to hyperventilation, high oxygen concentration, and light general anesthesia. At present an electrocardiogram is the only monitoring device used and this only in the more seriously ill.

Fluid given during the operation consisted mainly of 5 per cent dextrose in water containing the succinlycholine solution. Blood was administered only when preoperative anemia exists or excessive blood loss has occurred. Infants were rarely transfused, but blood loss becomes more of a problem as children increase in size.

Results

The age distribution of the patients in this series is presented in table 1. A few patients outside the pediatric age range were included because of the nature of their disease. We have not attempted to classify operative risk since all patients undergoing corrective surgery for congenital heart disease, except perhaps those with patent ductus arteriosus, are fair to poor risks. The types of operations which were performed and the mean duration of anesthesia are shown in table 2. This latter is included only to indicate the duration of succinylcholine administration in these children.

There were 19 hospital deaths in this series. This mortality rate is impossible to interpret without equating it against patients' diseases and surgical procedures performed. This is beyond the scope of this report; however, 15 of the 19 deaths were in patients less than one year of age, including 2 newborns. This high mortality rate in the very young has been the experience of others (9). There were no deaths attributable to anesthesia alone, no deaths during induction of anesthesia, and no deaths prior to surgical manipulation of the heart or great vessels.

During 115 of these anesthetics a careful record was kept of the total quantities of succinylcholine administered and the time during which apnea was maintained. These data (plus similar data of 80 additional patients undergoing open heart surgery) were transformed for each patient into micrograms of succinylcholine per kilogram of body

TABLE 1

AGE DISTRIBUTION OF 150 PATIENTS UNDERGOING CARDIOVASCULAR SURGERY

Age Range	Number of Patients	Per Cent of Patients
Less than 1 month	8	5
1–6 months	25	17
6–12 months	9	6
1–2 years	18	12
2–3 years	14	9
3–4 years	17	11
4–5 years	12	8
5–6 years	8	5
6–10 years	28	19
11–15 years	9	6
16–19 years	2	1

weight per minute necessary to maintain apnea. These data were plotted against age in years and the regression equation calculated ($Y = 291–15.8X$). The regression coefficient for this equation was found to be highly significant ($P < 0.01$) (10), indicating that an inverse linear relationship exists between age and dose of succinylcholine required to maintain apnea. When these data were broken down into age groups and their means plotted (table 3), it became apparent that a smooth curve more nearly expressed this relationship with high doses being required in children under one year and a constant low dose required after ten years (fig. 1). Linearity could be assumed between the ages of one and ten years. The projection of this curve to adult dosages indicated that approximately 90 μg./kg. per minute would be required to maintain apnea in adult patients. When measured in 14 adults the mean dose was found to be 92 μg./kg. per minute. This is greater than the figure of 50 μg./kg. per minute reported by Espinosa and Artusio (11) who measured the minimal apneic dose of adults.

In 5 patients the question of succinylcholine overdosage arose. These patients did not awaken promptly at the end of anesthesia and their respiration was irregular and inadequate. Four of these patients were also in congestive heart failure at that time, and it was difficult to distinguish between succinylcholine overdosage and cerebral anoxia

TABLE 2

TYPES OF SURGICAL PROCEDURES AND DURATION OF ANESTHESIA IN 150 PATIENTS

Surgical Procedure	Number of Patients	Mean Anesthesia Time in Minutes
Pulmonary valvulotomy	15	94
Blalock operation	22	105
Potts operation	34	108
Division patent ductus	49	90
Patent ductus and coarctation	4	154
Creation interatrial septal defect	9	130
Resection of coarctation	7	131
Transposition of pulmonary veins	2	157
Exploratory thoracotomy	6	103
Miscellaneous	2	170

from circulatory failure. The difficulty in this differential diagnosis is illustrated by the following case:

A 21-month-old female underwent surgery for patent ductus arteriosus with severe pulmonary hypertension. Because of the possibility of a reversed ductus, pressures in the great vessels were measured in the operating room. The pressure in the main pulmonary artery was equal to the aortic pressure. When the ductus was occluded there was no rise or fall in pulmonary artery pressure. The ductus was divided. The patient received 291 μg./kg. per minute of succinylcholine during the procedure. This dose was not excessive for her age group (mean for the 1 to 2 year group was 273 μg./kg. per minute). At the end of the operation, the patient did not awaken. The skin appeared mottled and cyanotic. Respirations were irregular, uncoordinated and inadequate. The liver was palpitated three fingerbreadths below the costal margin. The endotracheal tube was left in place and respirations were assisted with oxygen while the patient was rapidly digitalized intravenously. During the ensuing one hour, the liver size gradually receded to its preoperative size which was one fingerbreadth below the costal margin. Concomitantly, the patient became more responsive, her respiration more regular, and her skin color improved. One and one-half hours postoperatively, she no longer tolerated the endotracheal tube which was then removed. Convalescence was uneventful.

TABLE 3

Dose of Succinylcholine (μg./kg./min.) Necessary to Maintain Apnea During Anesthesia in Infants and Children by Age Groups

Age Range	Number of Patients	Succinylcholine (mcg./kg./min.) Mean ± S.E.*
Less than 1 month	8	447 ± 88
1–6 months	33	278 ± 18
6–12 months	24	297 ± 17
1–2 years	11	293 ± 18
2–3 years	15	238 ± 22
3–4 years	24	231 ± 15
4–6 years	20	200 ± 18
6–8 years	10	174 ± 24
8–10 years	11	136 ± 26
10–12 years	11	99 ± 12
12–16 years	14	98 ± 20
Adults	14	92 ± 20

* Standard Error of Mean.

In each of the 5 patients the endotracheal tube was left in place and respirations were assisted with oxygen. Three of the patients expired in the recovery room despite continued maintenance of adequate respiration. The dosage of succinylcholine used in each of these 3 children was below the mean for their age group. Congestive heart failure was the probable cause of death. The fourth patient, following an exploratory thoracotomy, had inadequate uncoordinated respirations for two hours postoperatively. This was treated by assisted respiration until full recovery of adequate respiration. The dose of succinylcholine in this child was substantially above the mean for his age group. Respiratory depression was probably due to excessive succinylcholine. The fifth patient was described above.

Three patients developed postoperative stridor, two without respiratory obstruction and one with respiratory obstruction. This last patient was discovered to have congenital subglottic stenosis at the time of intubation and has been reported elsewhere (12). Three attempts at intubation with progressively smaller tubes were necessary until only a 10 F tube could be passed in a six-month-old child. All three patients were treated with humidified oxygen without tracheotomy and recovered.

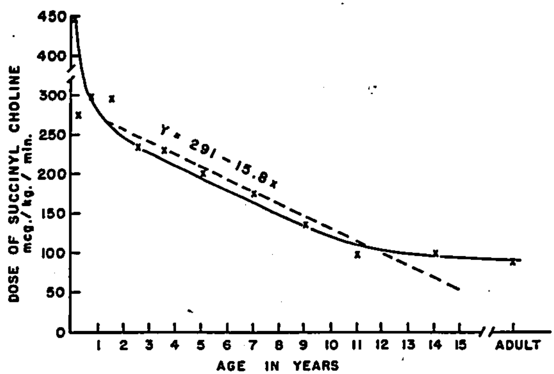

FIG. 1. Relationship of age to dosage of succinylcholine necessary to maintain apnea during general anesthesia in 195 patients (includes 80 patients who had undergone open heart surgery).

Other anesthetic complications which occurred in this series were not related to this particular anesthetic technique but were those which might occur with any endotracheal technique in children. They included: intubation of bronchus with too long an endotracheal tube; accidental dislodgement of a short endotracheal tube; introduction of an endotracheal tube too small to allow adequate ventilation by an insufflation system, requiring a second intubation, and postoperative hypothermia especially in infants weighing less than 15 pounds.

Discussion

The anesthetic technique and agents reported here are not new in anesthesiology. However, their application to cardiovascular surgery in infants and children possess certain obvious advantages which have proved highly successful for us. In using cyclopropane for induction, frequently we have observed arrhythmias, including severe bradycardia, premature ventricular contractions, nodal rhythm, and bigeminy. All these responded promptly to decreasing the concentration of cyclopropane. Similarly arrhythmias occurring on manipulation of heart under ether anesthesia were readily reversed by elimination of ether with oxygen. We have repeatedly observed that the heart became more amenable to manipulation when the anesthetic agent was decreased or eliminated. This was always possible when succinylcholine could be used to maintain proper operating conditions. In treating arrhythmias, procaine amide was used only twice and atropine three times early in this series of patients. We believe that oxygen is the best drug for treatment of arrhythmias. This anesthetic technique allows the use of at least 50 per cent oxygen for induction of anesthesia and at least 90 per cent during maintenance of anesthesia.

This method also allows the patient to be awake and in control of his reflexes immediately at the end of surgery. Congestive heart failure, circulatory collapse, pulmonary edema, and cerebral anoxia are not rare complications of surgery in these patients in the immediate postoperative period. It is important that these complications be promptly recognized and treated. This can be most readily done when the signs and symptoms of such complications are not confounded by the persisting effects of anesthetic agents. All drugs administered during this anesthetic technique (except for premedication drugs) are practically eliminated or rendered inactive by the time the patient reaches the recovery room.

Much concern has been expressed in the past over the complications of endotracheal intubation of infants and children. The data collected by Pender (13) indicate that intubation provides no greater hazard in the child than the adult provided intubation is not traumatic and movement of the larynx on the endotracheal tube does not occur by movement of the head or swallowing. The use of succinylcholine prevents these precipitating causes. Complete relaxation is achieved by succinylcholine allowing easy introduction of a large endotracheal tube without trauma. Continued administration of succinycholine prevents swallowing during light anesthesia. Laryngeal edema has not occurred in this series except in the one patient with a laryngeal abnormality.

Moderate hypothermia has been recommended for routine use in patients such as we are reporting here, at least in the cyanotic ones (9). In some of our patients hypothermia has occurred despite our efforts to prevent it. We do not believe that any of the deaths or complications in this series would have been prevented through the routine use of hypothermia.

The relationship of age to the apnea-dose of succinylcholine provides an interesting speculation. Assuming that the dose of succinylcholine necessary to produce apnea (complete paralysis) is proportional to the number of myoneural junctions in the body, then the inverse relationship shown here between age and the dose per kilogram of body weight could be explained by postulating that children and adults have the same number of myoneural junctions. If this be true then the infant would require a larger dose of succinylcholine calculated on a weight basis. With growth the number of myoneural junctions per unit of body weight would decrease and with it the dose necessary to produce apnea.

SUMMARY

An anesthetic technique for cardiovascular surgery in infants and children has been described, and the results of its use during 150 surgical procedures for correction of congenital heart disease has been presented.

This method which utilizes light general anesthesia, controlled respiration, and succinylcholine administration has these advantages: more than 90 per cent oxygen can be used throughout most of the anesthetic period, extensive manipulation of the heart can be accomplished without precipitation of dangerous arrhythmias, ideal operating conditions are provided for the surgeon, and the patients are completely awake at the end of the operative procedure.

Data have been presented which indicate that children are more resistant than adults to the effects of succinylcholine.

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