CLINICAL REPORTS

Ronald D. Miller, M.D., Editor

Anesthesiology
65:428–431, 1986

The Optimum Site and Strength–Duration Relationship of Transesophageal Indirect Atrial Pacing

DAVID C. CHUNG, M.D., F.F.A.R.C.S., F.R.C.P.(C),* GARRY E. TOWNSEND, M.D., F.R.C.P.(C),†
CHARLES R. KERR, M.D., F.R.C.P.(C)‡

The use of a transesophageal electrode for the purpose of cardiac pacing was first suggested by Zoll[1] in 1952, and the feasibility of this technique was demonstrated soon afterward by Shafiroff and Linder.[2] Subsequently, this technique has been used for ventricular pacing in cardiac emergencies with variable success,[3–7] and Stopczyk *et al.* elected to use this route for atrial pacing.[8] The first large series using transesophageal atrial pacing as a means of treating hemodynamically significant sinus bradyarrhythmia in anesthetized patients was reported by Backofen *et al.*[9] in 1984. In this report the authors recommended introducing the bipolar electrode orally to a distance of approximately 35 cm from the teeth and using a pulse strength of 25 mA and a pulse duration of 20 ms. This current study was undertaken to determine the atrial stimulation threshold at different levels of the distal esophagus and to delineate the relationship between pulse strength and pulse duration (the strength–duration relationship) with respect to atrial capture.

METHODS

Data were collected from 11 subjects: six ASA Class I surgical patients receiving halothane anesthesia for orthopedic or gynecologic procedures and five otherwise healthy patients requiring transesophageal pacing for the investigation of paroxysmal supraventricular tachyarrhythmias. The experimental protocol was approved by the Clinical Screening Committee for Research and Other Studies Involving Human Subjects of our institution, and all subjects gave informed consent.

The pacing lead used was the Medtronic® 6992. It has a bipolar electrode with a 2.9 cm interpolar distance, and the distal pole was used as the cathode (the negative electrode). The pulse generator used was a variable-rate unit capable of generating a rectangular pulse against resistors up to 2,000 ohm (a constant-pulse generator). Its pulse strength is adjustable between 0 and 37.5 mA and its pulse duration between 0 and 9.9 ms. Pacing was carried out at rates 15–20% above the patients' sinus rates. All subjects were monitored by ECG (lead II or CS_5) and sphygmomanometry during the study, and all anesthetized subjects were cared for by an anesthetist not involved with carrying out the protocol.

Stimulation Thresholds in the Distal Esophagus. This determination was performed in all 11 subjects. Using surface landmarks as a guide, the electrode was inserted into the esophagus transorally until the distal pole (the cathode) was at the level of the fifth interspace anteriorly in five of the anesthetized subjects. After recording the depth of insertion of this pole as its distance from the upper incisors, atrial stimulation threshold was determined by applying a pulse of 9.9 ms duration and increasing the strength rapidly until consistent atrial capture was achieved, then decreasing the strength gradually until reaching the point at which capture was first lost. This procedure was repeated at proximal sites by withdrawal of the electrode 1 cm at a time until the distal pole was at the level of the second interspace. In the other six subjects, the electrode was introduced transnasally, and stimulation thresholds at various depths of insertion measured from the nares were similarly determined.

Strength–Duration Relationship. In this part of the study the electrode was repositioned at the point of minimum stimulation threshold as determined earlier, and threshold current required to capture the atria at pulse durations from 1 to 9.9 ms, at 1 ms increments, were determined. Atrial capture was considered not possible if the required

* Associate Professor.
† Assistant Professor.
‡ Associate Professor.

Received from the *Department of Anaesthesia, University of Western Ontario, London, Canada, and the †Department of Anesthesiology and the ‡Division of Cardiology, University of British Columbia, Vancouver, Canada. Accepted for publication May 13, 1986. Completed during the tenure of a Detweiler Travelling Fellowship in the Division of Cardiology, University of British Columbia, Vancouver, Canada. Presented in part at the American Society of Anesthesiologists Annual Meeting, October 1985.

Address reprint requests to Dr. Chung: University Hospital, P.O. Box 5339, Station A, London, Ontario, Canada, N6A 5A5.

Key words: Heart: arrhythmia; bradycardia; pacemaker, transesophageal.

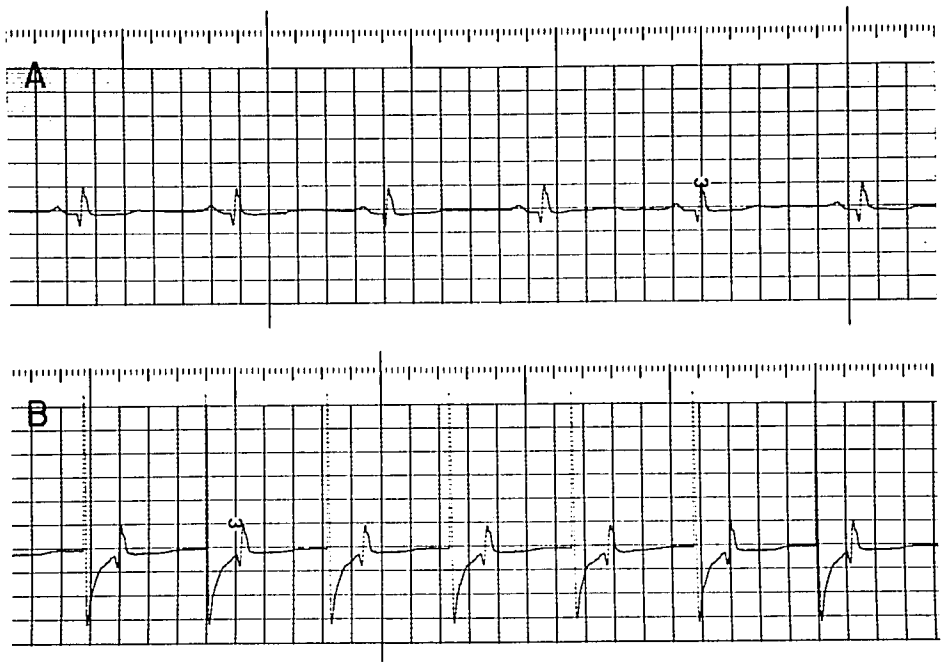

FIG. 1. ECG trace of a patient in sinus rhythm (*A, upper*) and paced rhythm (*B, lower*). The QRS morphologies in *A* and *B* are identical, confirming that transesophageal pacing in this instance is indirect atrial pacing.

pulse strength was greater than 25 mA. The plot between threshold current and pulse duration, known as the strength–duration relationship, was determined in the six anesthetized subjects only.

RESULTS

Stimulation Threshold in the Distal Esophagus. The mean (±SD) age of the 11 subjects was 38 (±18) yr, the range 19–78 yr; their mean (±SD) height was 174 (±8) cm, the range 162–186 cm. An ECG trace demonstrating transesophageally paced atrial rhythm appears in figure 1, and the characteristic relationship between stimulation threshold and depth of electrode insertion from a representative patient is illustrated in figure 2. The transesophageal atrial stimulation threshold was extremely high at the distal end of the esophagus, and it fell gradually to a minimum as the electrode was moved proximally—but only to rise again at even more proximal sites. This discrete site of minimum stimulation threshold could be identified in each subject. In addition to this site, segments of the distal esophagus with modest stimulation thresholds could also be identified. It can be seen from the example in figure 2 that between 34 and 38 cm, the threshold was 10 mA or less; and between 34 and 40 cm, the stimulation threshold was 15 mA or less.

Because there was no statistical difference between the minimum stimulation threshold of anesthetized and conscious subjects and no difference between the depth of

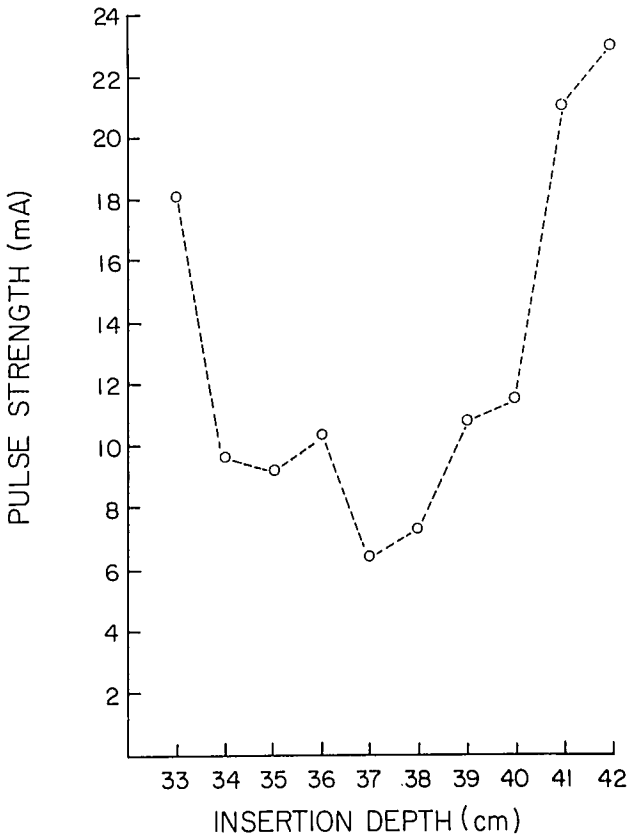

FIG. 2. A typical relationship between atrial stimulation threshold and depth of electrode insertion. (See text for details.)

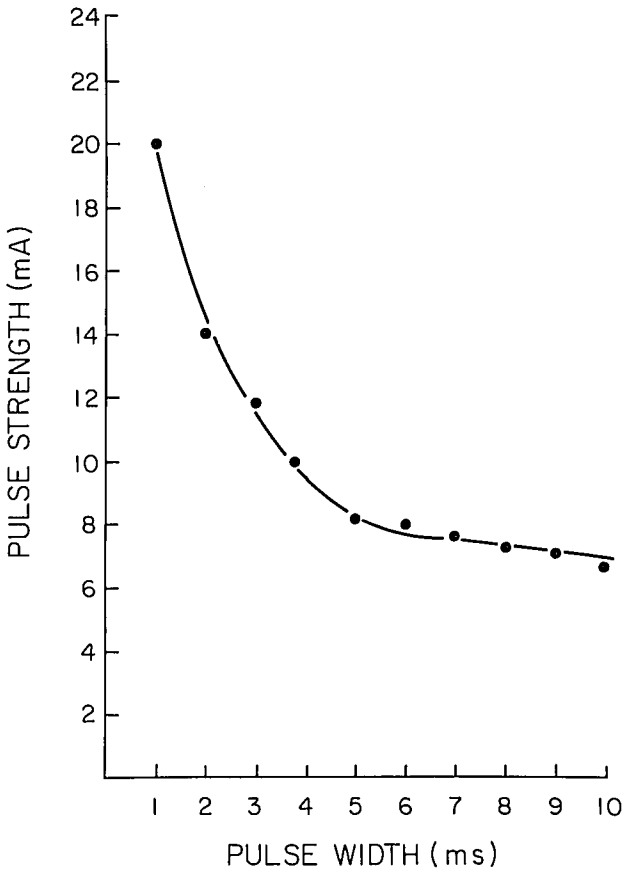

FIG. 3. A typical strength–duration relationship. (See text for details.)

this site and the height of patients with transoral electrodes and those with transnasal electrodes, results from all 11 subjects were combined for analysis. The mean (±SD) minimum atrial stimulation threshold of the entire group was 6.5 (±1.4) mA, the range being 4.6–9.3 mA. The mean (±SD) depth of this site was 36 (±2) cm, the range being 33–40 cm. Between an average depth of 35 and 38 cm, the atrial stimulation threshold was 10 mA or less; between an average depth of 34 and 40 cm, the atrial stimulation threshold was 15 mA or less.

Strength–Duration Relationship. During determination of the strength–duration relationship, atrial capture with a threshold current equal to or less than 25 mA was successful only in two of six patients when the pulse duration was 1 ms and only in five of six patients when the pulse duration was 2 ms. When the pulse duration was 3 ms or longer, atrial capture with a current less than 25 mA was successful in all six patients. A representative strength–duration relationship from one subject is illustrated in figure 3. In all six subjects the threshold strength fell rapidly as the pulse duration increased from 1 ms to 5 ms; any further fall in threshold strength between 5 and 9.9 ms was only small (less than 1.5 mA).

Other Observations. Intermittent ventricular capture with a pulse strength greater than 23 mA was observed in one of the anesthetized subjects. This occurred at sites 5 cm distal to the site of minimum atrial stimulation threshold and beyond. Otherwise, no arrhythmias were observed in any of the patients; neither was phrenic nerve pacing a complication. All conscious subjects described a tingling, burning, or fluttering yet tolerable sensation in the precordium during pacing; these same subjects experienced an urge to cough when pacing from a site 3 or more cm proximal to the site of minimum atrial stimulation threshold. No other complications were observed, and no post-pacing discomfort was reported by our subjects.

DISCUSSION

As in other forms of cardiac pacing, determining the site of minimum threshold and the strength–duration relationship of transesophageal atrial pacing has important clinical implications. Pacing from the site of minimum threshold can ensure consistent capture and avoid rapid depletion of the power source; and the strength–duration relationship can be used to select the optimum pulse for pacing.

Our results show that a discrete site of minimum atrial stimulation threshold less than 10 mA exists in the distal esophagus at an average depth of 36 cm from the upper incisors or from the nares of adult patients. In addition, there are short segments with thresholds between 10 and 15 mA spanning this site. With respect to the strength–duration relationship, stimulation threshold falls precipitously when pulse width increases from 1 to 5 ms but remains almost constant between 5 and 10 ms. Although it is shifted upward and to the right, the shape of this curve is quite similar to that of direct epicardial or endocardial pacing. That is, transesophageal atrial pacing requires a stronger pulse of longer duration than direct atrial stimulation.

In situations when sinus bradyarrhythmia is anticipated and prophylactic placement of the electrode is necessary, locating the site of minimum threshold as described is advised, and pacing can commence at a pulse strength close to the threshold strength as required. Unfortunately, the procedure of locating this site is time-consuming and impractical in an emergency. When rapid establishment of atrial pacing is necessary, we recommend placement of the distal pole of the bipolar electrode (cathode) to a depth of 36 cm from the upper incisors or from the nares of adult patients—a depth consistent with that recommended by Backofen *et al.*[9] In addition, we recommend that the pulse duration to be set at 10 ms. With this pulse width, and with a pulse strength of 15 mA, atrial capture of patients with cardiac disease (including cardiomyopathy and ischemic heart disease) occurred in most instances.[10]

Even higher pulse strength may be required in rare circumstances, but increasing pulse duration beyond 10 ms will not decrease threshold strength and is not necessary because the strength–duration relationship is already flat between 5 and 10 ms.

We conclude that transesophageal atrial pacing is safe and has few complications. We have not had complaints suggestive of esophageal burns in our subjects, and the absence of this potential complication is confirmed by the report of Burrack and Furman[3] and that of Shaw *et al.*[5] In our experience and in that of others, inadvertent ventricular capture and pacing of intrathoracic motor nerves are rare in adult patients.[11,12] Signs of tracheal irritation (*e.g.*, coughing in conscious subjects), however, are common when the pacing electrode is too far proximal to the site of minimum stimulation threshold. In this instance, advancing the electrode for 2–3 cm distally will increase its distance from the carina, decrease the current required to capture the atria, and eliminate this complication.

References

1. Zoll PM: Resuscitation of the heart in ventricular standstill by external electric stimulation. N Engl J Med 247:768–771, 1952
2. Shafiroff BGP, Linder J: Effects of external electrical pacemaker stimuli on the human heart. J Thorac Surg 33:544–550, 1957
3. Burrack B, Furman S: Transesophageal cardiac pacing. Am J Cardiol 23:469–472, 1969
4. Lubell DL: Cardiac pacing from the esophagus. Am J Cardiol 27: 641–644, 1971
5. Shaw RJ, Berman LH, Hinton JM: Successful emergency transoesophageal cardiac pacing with subsequent endoscopy. Br Med J 284:309, 1982
6. Cooper DN: Temporary cardiac pacing *via* the oesophagus. Postgrad Med J 58:45–46, 1982
7. Black DA: Emergency transoesophageal cardiac pacing. Br Med J 284:1263, 1982
8. Stopczyk MJ, Zochowski RJ, Sadowski Z: P wave triggered permanent atrial pacing in a case of transient sinus arrest. Br Heart J 34:318–321, 1972
9. Backofen JE, Schauble JF, Rogers MC: Transesophageal pacing for bradycardia. ANESTHESIOLOGY 61:777–779, 1984
10. Kerr CR, Chung DC, Mason MA: Termination of spontaneous atrial flutter by transesophageal atrial pacing (abstract). Circulation 72:III-174, 1985
11. Gallagher JJ, Smith WM, Kerr CR, Kasell J, Cook L, Reiter M, Sterba R, Harte M: Esophageal pacing: A diagnostic and therapeutic tool. Circulation 65:336–341, 1982
12. Benson DW Jr, Sanford M, Dunnigan A, Benditt DG: Transesophageal atrial pacing threshold: Role of interelectrode spacing, pulse width and catheter insertion depth. Am J Cardiol 53: 63–67, 1984

Anesthesiology
65:431–435, 1986

The Effect of Different Methods of Inducing Anesthesia on Intraocular Pressure

SHYAMALA K. BADRINATH, M.D.,* AFZAL VAZEERY, M.D., PH.D.,† ROBERT J. MCCARTHY, PHARM.D.,* ANTHONY D. IVANKOVICH, M.D.‡

Patients with penetrating eye injuries frequently require induction of general anesthesia and rapid endotracheal intubation with a technique that does not produce increases in intraocular pressure (IOP). Previous studies have shown that thiopental,[1] narcotic analgesics,[2] and volatile inhaled anesthetics[3] all lower IOP, with the possible exception of ketamine.[4] The nondepolarizing neuromuscular blocking drugs also minimally affect IOP. Atracurium is a nondepolarizing neuromuscular blocking agent that has a rapid onset and shorter duration of action than pancuronium.[5,6] Atracurium has also demonstrated minimal cardiovascular effects, making it ideal for rapid-sequence endotracheal intubation. A comparison of IOP responses to rapid-sequence induction and endotracheal intubation with different anesthetics in various doses has not been described. The purpose of the present study, therefore, was to compare the IOP and cardiovascular changes during rapid-sequence induction employing atracurium-facilitated endotracheal intubation with various combinations of iv anesthetics.

* Assistant Professor.
† Research Assistant.
‡ Professor.
Received from the Department of Anesthesiology, Rush Presbyterian St. Luke's Medical Center, 1753 W. Congress Parkway, Chicago, Illinois 60612.
Address reprint requests to Dr. Ivankovich.
Key words: Anesthetics, intravenous: etomidate; ketamine; thiopental. Eyes: intraocular pressure. Neuromuscular relaxants: atracurium.

Materials and Methods

The study was approved by the Human Investigation Committee of the hospital. The purpose and the procedure of this investigation were explained to all patients by one of the investigators prior to surgery, and an informed consent obtained. Seventy patients (39 females, 31 males) ages 15–76 yr, weighing 45–111 kg (ASA Class I and II), and scheduled for elective nonocular surgery