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Intraoperative Esophageal Electrocardiography for Dysrhythmia Analysis and Therapy in Pediatric Cardiac Surgical Patients

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Cardiac dysrhythmias frequently complicate pediatric congenital heart surgery.[1] The proximity of intracardiac surgical repair to conduction tissue and the presence of residual hemodynamic abnormalities are associated with a high incidence of dysrhythmias in these patients.[2,3] Because correct diagnosis of tachyarrhythmias in the immediate postcardiopulmonary bypass period may have therapeutic and prognostic importance, rapid and accurate diagnosis is essential.[4,5]

Intraoperative diagnosis of tachyarrhythmias can be difficult from the standard surface electrocardiogram because P wave identification, essential for definitive diagnosis, is not always possible.[6] This is especially true in pediatric patients with faster intrinsic heart rates and a high incidence of tachyarrhythmias.[7,8] Atrial epicardial electrograms (AEG) are a precise and accurate technique for the analysis of complex cardiac dysrhythmias in surgical patients; however, this requires placement of temporary epicardial atrial pacing wires and is not always available intraoperatively.[6] Esophageal electrocardiography is another valuable tool for dysrhythmia analysis.[9–12] Monitoring the ECG from an electrode within the esophagus proximal to atrial tissue permits clearer identification of the relationship of atrial to ventricular activity.[13] The value of the esophageal lead for intraoperative dysrhythmia analysis has been demonstrated in adult cardiac surgical patients.[14]

Considering the limitations of the surface electrocardiogram and the difficulties of dysrhythmia analysis in pediatric patients, this prospective investigation was designed to examine the usefulness of the esophageal electrogram (EsEG) for dysrhythmia analysis and therapeutic decisions during pediatric cardiac surgery.

METHODS

After approval by the Institutional Review Board and informed parental consent, 15 pediatric patients (ages 1 day to 7 yr) scheduled for intracardiac repair of congenital defects requiring cardiopulmonary bypass (CPB) were studied. All patients had a normal sinus rhythm preoperatively; however, three patients had electrophysiologic evidence of Wolff-Parkinson-White syndrome. One patient received quinidine and another received digoxin for the preoperative management of supraventricular tachycardia.

Intraoperative electrocardiographic monitoring included capability for a 7-lead surface ECG consisting of leads I, II, III, AVR, AVL, AVF, and V_5, with a lead selector switch. A Grass® Recording System provided simultaneous recording of three ECG leads. A pediatric EsEG¶ was designed to our specifications as a no. 12 French product-line extension of the Cardio-Esophascope® (Portex Inc., Wilmington, MA). The esophageal ECG catheter had two conductive plastic electrodes 0.5 cm in width and situated 2.0 cm apart at the distal end of the stethoscope. Each electrode wire was extruded through the catheter wall at the proximal end of the catheter. An electrocautery protection filter (Hewlett-Packard No. 14392A) consisting of a 3 mHz inductor and a 10 K/ohm resistor was incorporated into the EsEG circuit between the lead wires and monitoring cable. Connection of the esophageal leads to the right arm and left arm electrodes of a second lead I ECG circuit established a bipolar EsEG. All of the ECG monitors were electrically isolated, and the electrograms were recorded at a paper speed of 25 mm/s with a calibration of 1 millivolt = 10 mm.

Following anesthetic induction and endotracheal intubation, the esophageral catheter was inserted orally and positioned to produce maximum A wave amplitude representing atrial depolarization on the EsEG. The time

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TABLE 1. Comparison of Standard Surface ECG with Esophageal Electrocardiogram (EsEG) for Correct Dysrhythmia Diagnosis

	Correct Diagnosis of Dysrhythmias (%)		
	Surface ECG	EsEG	Surface ECG plus EsEG
Intraoperative analysis			
Cardiac anesthesiologist	19*	98	98
Postoperative analysis			
Cardiac anesthesiologist	16*	90	94
Pediatric cardiologists	17*	93	96

* $P < 0.05$ for surface ECG *vs.* EsEG, surface ECG plus EsEG.

required for placement was recorded and thereafter, the position of the stethoscope was not changed. The 7-lead surface ECG and the bipolar EsEG were simultaneously recorded at 7 predefined intervals: presternotomy, poststernotomy, rewarming at 35° during CPB, just prior to terminating CPB, 15 min, and 1 h after CPB and at the completion of surgery. Three electrocardiographic monitoring modes were used for dysrhythmia analysis during each recording interval: 1) 7-lead surface ECG; 2) EsEG; and 3) simultaneous 7-lead surface ECG plus EsEG. Intraoperative diagnosis by the attending cardiac anesthesiologist was recorded during each interval. The same sequence of ECG and EsEG recordings totaling 315 rhythm strips was also blindly analyzed postoperatively by two pediatric cardiologists and another cardiac anesthesiologist. All episodes of dysrhythmias observed during the study intervals and any associated therapeutic interventions were recorded. In addition, the AEG was recorded from a pair of atrial pacing wires that were placed during rewarming and monitored to provide a standard for comparison of the other electrograms.

The incidence of correct diagnosis of dysrhythmias using the surface ECG and the EsEG was compared using the Chi-square method. Statistical significance was assumed at $P < 0.05$ level. Results are presented as a mean ± SEM.

RESULTS

Both the EsEG and the AEG produced equally distinct A and V wave deflections, representing atrial and ventricular depolarization, respectively. The temporal relationship between atrial and ventricular activation was always obvious and provided information for conclusive dysrhythmia diagnosis.

Fifty-six episodes of sustained dysrhythmias occurred in the 15 patients during the specified recording intervals. Analysis of the 7-lead surface ECG recordings by the cardiac anesthesiologist and independent postoperative analysis of the same recordings by another cardiac anesthesiologist and two pediatric cardiologists demonstrated a correct diagnosis of dysrhythmias in only 19%, 16%, and 17% of the cases, respectively (table 1). Definitive dysrhythmia analysis using the EsEG or the EsEG plus surface ECG produced a significantly greater incidence of correct diagnosis than the ECG alone ($P < 0.05$) (table 1). Tachyarrhythmias were consistently the most difficult dysrhythmia to diagnose by surface ECG alone (fig. 1).

Seventy-four per cent of the dysrhythmias occurred at the termination of CPB or in the immediate post-CPB

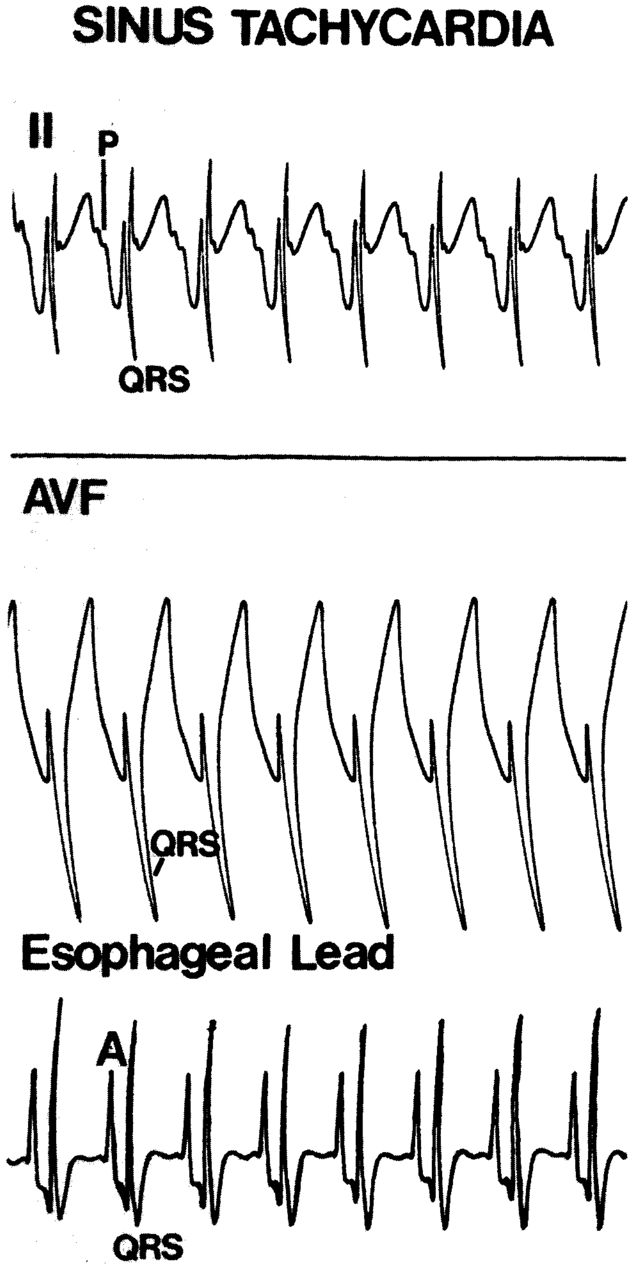

FIG. 1. Indistinct P waves in leads II and AVF preclude definitive diagnosis in this 4-day-old infant. The simultaneous EsEG shows regular distinct A waves and a constant A–QRS interval, allowing for the correct diagnosis of sinus tachycardia.

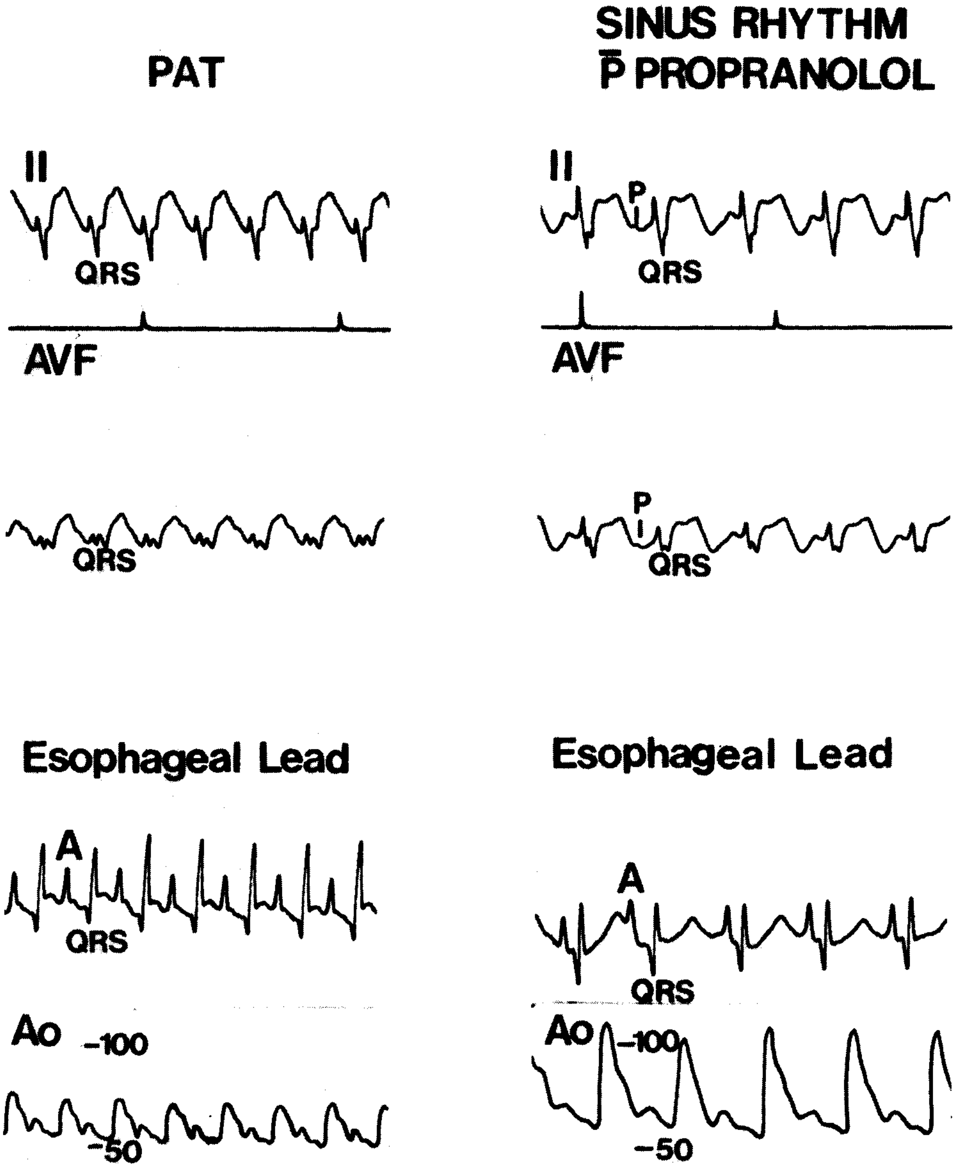

FIG. 2. Conventional leads II and AVF indicate a limited diagnosis of a narrow QRS tachycardia of uncertain origin due to lack of P wave identification in this 7-month-old hypotensive infant. The simultaneous EsEG clearly depicts paroxysmal atrial tachycardia (PAT) at a rate of $240 \cdot min^{-1}$, indicating propranolol therapy that converted the PAT to a sinus rhythm, resulting in a significant increase in blood pressure.

period. The most common dysrhythmias were sinus tachycardia (as defined by heart rates greater than two standard deviations from the mean, according to the Ziegler tables),[15] supraventricular tachycardia, junctional tachycardia, atrioventricular (AV) dissociation with a rapid ventricular response, third degree AV block, second degree AV block, and ventricular tachycardia. Seventy-two per cent of the 56 dysrhythmias required a therapeutic intervention. Diagnostic information necessary for dysrhythmia-specific therapy was obtainable from the EsEG in 67% of the cases, while therapy for only 22% of the cases could have been correctly directed by the surface ECG alone ($P < 0.05$) (fig. 2). The esophageal lead also documented the progression of various rhythm disturbances in the post-CPB period.

The modified esophageal stethoscope provided for clear auscultation of heart and lung sounds in all patients. Time required for adequate positioning of the esophageal lead was always less than 3 min, and all attempts at using the esophageal lead were successful. There was no morbidity associated with the use of the EsEG.

Discussion

Definitive analysis of the cardiac rhythm requires identification of atrial electrical activity and the atrial–ventricular activation sequence. Although the intraoperative surface ECG is adequate for recognition of ventricular depolarization, identification of atrial activity is often difficult due to low amplitude characteristics of the P wave.

This is especially true for pediatric patients whose rapid heart rates often conceal the P wave within the T wave. This study demonstrates the diagnostic limitations of the surface ECG because less than 20% of the dysrhythmias were correctly diagnosed. Alternate ECG electrode placement, such as CB_5 and the MCL leads, have been used to observe P wave activity; however, those studies of adult patients with slower intrinsic heart rates may not reflect analysis problems in infants and children.[16] Furthermore, the amplitude of the P waves in the MCL and the CB_5 leads is much lower than the A wave of the EsEG.

Our study shows that intraoperative esophageal electrocardiography is a useful tool for dysrhythmia analysis during pediatric cardiac surgery and can overcome the inaccuracies of surface ECG monitoring. The EsEG was frequently necessary for implementing appropriate antiarrhythmic therapy. Because correct dysrhythmia analysis has been shown to improve therapeutic results, accurate analysis is essential.[5] In our study, a significantly greater number of dysrhythmia-specific therapeutic interventions could be initiated by the information gained from the EsEG when compared with the surface ECG.

The esophageal ECG can be monitored as a bipolar or unipolar ECG circuit. Most investigators have found the bipolar esophageal ECG to be superior because the A waves were more distinct and more sensitive to alterations in atrial depolarization patterns.[17] Our preliminary trials with these two methods demonstrated enhanced A wave amplification and less baseline fluctuation with the bipolar EsEG in the anesthetized, mechanically ventilated patient. When the EsEG is monitored, electrical safety precautions must be strictly followed by using electrocardiographic equipment that is electrically isolated and adheres to the standards of the American Heart Association. Further patient protection is provided by inserting an electrocautery protection filter into the ECG circuit.

In conclusion, this study demonstrates the value of the esophageal lead for diagnosis and therapy during pediatric cardiac surgery. The frequency of complex tachyarrhythmias associated with intracardiac repair of congenital heart defects emphasizes the usefulness of the esophageal electrogram in this patient population.

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