

# Transcutaneous Cardiac Pacing in Patients with Automatic Implantable Cardioverter Defibrillators and Epicardial Patch Electrodes

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In patients with automatic implantable cardioverter defibrillators, insulation of the epicardial patch electrodes (patches) prevents externally applied current from passing through the electrode to the cardiac muscle so that external transthoracic and even internal defibrillation can be unsuccessful. Because emergency cardiac pacing may be required in such a case, a study was performed to evaluate whether, and at what threshold and electrode orientation, transcutaneous pacing is possible in patients with implanted patches. Thresholds for transcutaneous pacing were determined during general anesthesia in nine patients with patches sewn across the heart (anterior right and posterior left ventricles) either before or after surgery, or at both times (automatic implantable cardioverter defibrillator implantation/exchange with or without coronary artery bypass grafting). Because surgery *per se* can increase the pacing threshold, nine patients of similar body size and weight undergoing routine coronary artery bypass grafting also were evaluated and served as a control group. Pacing thresholds (stimulus duration: 50 ms) were determined during normothermia with a transportable transcutaneous pacer, and adult cutaneous electrodes were placed across the patients' chest in the standard anteroposterior and right-to-left orientations. In all patients with patch electrodes, anteroposterior pacing was possible at a mean threshold of  $73 \pm 30$  mA standard deviation (range: 40-140 mA). This threshold was not significantly different (Mann-Whitney test) from that in control patients before ( $57 \pm 20$  mA; range: 30-90 mA) or after ( $94 \pm 24$  mA; range: 40-120 mA) coronary artery bypass grafting. The surgical procedure *per se* significantly increased the threshold (Wilcoxon test,  $P < 0.05$ ). Right-to-left pacing was possible (threshold  $< 150$  mA) in only four patients with patches and in one without patches. Thus, emergency noninvasive transcutaneous cardiac pacing is possible at normal thresholds in patients with implanted patches. In contrast, right-to-left pacing was rarely effective and therefore does not represent an acceptable alternative in patients in whom standard anteroposterior pacing landmarks are not accessible. (Key words: Complications: bradycardia; cardiac arrest; ventricular fibrillation. Heart, pacemakers: transcutaneous; transthoracic. Resuscitation, cardiopulmonary: automatic implantable cardioverter defibrillator; defibrillation; pacing.)

MORE THAN 18,000 automatic implantable cardioverter defibrillators (AICDs) have been inserted world wide<sup>1</sup> in patients with a history of sudden cardiac death or malignant ventricular arrhythmias refractory to pharmacologic therapy. Usually, this involves surgical implantation of two epicardial defibrillation patch electrodes (patches) sewn across the heart and, in most cases, connected to an AICD device.<sup>2</sup>

Because the insulation of the patches prevents externally applied current from passing through the electrode to the cardiac muscle,<sup>3,†</sup> transthoracic defibrillation can be difficult with routine cardiopulmonary resuscitation (CPR) protocols.<sup>3,4,¶</sup> In fact, patch implantation has been demonstrated to increase markedly the threshold for, and decrease the chance of, successful transthoracic defibrillation in anesthetized dogs and calves.<sup>3,5</sup> Similarly, in humans with implanted patches, transthoracic and even open-chest defibrillation with internal paddles can be unsuccessful.<sup>4,6</sup>

In patients with an AICD, the need may arise for temporary cardiac pacing (*e.g.*, after coronary artery bypass grafting [CABG]), often performed simultaneously with patch implantation, during anesthesia for AICD exchange or other procedures, or secondary to bradycardia associated with antiarrhythmic drugs. We therefore undertook a prospective evaluation of whether and at what threshold noninvasive transcutaneous cardiac pacing is possible in patients with implanted patches. Because position of the cutaneous electrodes relative to the patches can affect pacing efficacy, we assessed thresholds with the pacing electrodes in both the anteroposterior (axis parallel to patches) and right-to-left (perpendicular to patches) orientations.

## Materials and Methods

After having received approval by the local university's ethics committee and having obtained informed written consent, we performed transcutaneous cardiac pacing

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¶ Physicians manual. Ventak® P AICD™ models 1600 and 1610: Automatic implantable cardioverter defibrillator. St. Paul, Minnesota, Cardiac Pacemakers, Inc., 1989, p 53.

during general anesthesia in 18 patients (American Society of Anesthesiologists physical status 3 or 4) either before or after surgery, or at both times.

STUDY POPULATION

Nine patients had patches sewn to the right (anterior patch) and left (posterior patch) ventricles. Of these patients, four were studied both before and after AICD implantation with (n = 3) or without (n = 1) simultaneous CABG (median sternotomy, hypothermic cardiopulmonary bypass, intermittent aortic cross-clamping). Patches had been implanted 19–48 months previously in the remaining five patients, four of whom had patches placed at the time of CABG. These latter patients were studied while being operated on for exchange of the AICD located in the anterior abdominal wall. Patients with implanted patches had severe malignant tachyarrhythmias and had suffered at least once from an episode of sudden cardiac death. The patients' physical, surgical, and medical characteristics are depicted in table 1. In these patients, antiarrhythmic drugs (including digoxin) had been discontinued before surgery.

Because cardiac surgery *per se* can increase the threshold required for transcutaneous pacing,<sup>7</sup> nine patients undergoing routine CABG also were evaluated and served as a control group. Physical characteristics, anesthetic, and surgical procedures were similar to those in patients with an implanted AICD, except that no patches were present.

The anesthetic regimen was left to the discretion of the anesthesiologist in charge of the case, but uniformly consisted of a fentanyl/enflurane (in oxygen)/pancuronium bromide-based technique with infusion of cardiovascular drugs as required. In some patients, small doses of thiopental were used during induction.

AUTOMATIC IMPLANTABLE CARDIOVERTER DEFIBRILLATOR DEVICE

Patches (approximately 5 × 6 cm, model L 67, Cardiac Pacemakers, Inc., St. Paul, MN) were sewn across the heart as indicated above, with slight positional deviations if required for CABG. For sensing, two unipolar screw-in electrodes were inserted into the myocardium. Patch and sensing leads were tunneled and connected to the AICD. To ensure proper sensing and defibrillation, all

TABLE 1. Physical and Medical Characteristics of Study Population and Individual Threshold Values for Transcutaneous Anterior-Posterior Cardiac Pacing in Patients with and without Epicardial Defibrillation Patch Electrodes

Patient	Surgical Procedure	Pacing Threshold (mA)		Weight (kg)	Height (cm)	Past Medical History
		Before Surgical Procedure	After Surgical Procedure			
Patients with implanted epicardial defibrillation patch electrodes (n = 9)						
1	AICD implantation + CABG	140	140	105	174	CAD, atrial fibrillation, obesity
2	AICD implantation + CABG	60	70	84	178	CAD, s/p AMI + PMI
3	AICD implantation + CABG	60	100	71	165	CAD, s/p AMI + PMI
4	AICD exchange	Not measured	50	77	170	CAD, s/p AMI, CABG, resection of VA + AICD implantation, hypertension, diabetes
5	AICD exchange	Not measured	60	110	176	CAD, s/p PMI, CABG + AICD implantation, hypertension, obesity
6	AICD exchange	Not measured	80	68	160	CAD, s/p AMI, CABG + AICD implantation
7	AICD exchange	Not measured	40	75	175	CAD, s/p PMI, CABG + AICD implantation
8	AICD exchange	Not measured	60	78	167	CAD, s/p AMI with VA, AICD implantation
9	AICD implantation	50	60	87	180	CAD, s/p PMI, hypertension
Mean ± SD		73 ± 30		84 ± 15	172 ± 7	
Patients without epicardial defibrillation patch electrodes (n = 9)						
10	CABG	70	100	104	192	CAD, hypertension
11	CABG	50	90	86	162	CAD, s/p AMI, hypertension, diabetes
12	CABG	40	90	97	182	CAD,
13	CABG	40	120	84	171	CAD, hypertension
14	CABG	30	40	55	149	CAD, s/p AMI, hypertension
15	CABG	50	100	100	182	CAD, s/p PMI, hypertension
16	CABG	80	120	94	161	CAD, s/p AMI + PMI, diabetes
17	CABG	90	90	76	169	CAD, hypertension, diabetes
18	CABG	60	100	93	182	CAD, s/p AMI + PMI, moderate COPD
Mean ± SD		57 ± 20	94 ± 24	88 ± 7	172 ± 14	

AICD = automatic implantable cardioverter defibrillator; CABG = coronary artery bypass grafting; CAD = coronary artery disease; VA = ventricular aneurysm; AMI = anterior myocardial infarction;

PMI = posterior myocardial infarction; COPD = chronic obstructive pulmonary disease; AP = anterior-posterior; s/p = status post.

procedures involved at least one fibrillation and defibrillation trial *via* the AICD system. During the study and surgery, the AICD was deactivated to avoid damage and interference by cautery.

### TRANSCUTANEOUS PACING

After the skin was cleaned with alcohol, pacing was performed in the VVI mode with a transportable pacer (model Pace 500 D, Osypka, Grenzach, Germany), with two circular (diameter 13 cm; effective electrode area 50 cm<sup>2</sup>) cutaneous adult pacing electrodes being placed across the patients' chest in the standard anteroposterior direction. In accordance with clinical practice and the manufacturer's recommendation, the negative (cathodal) electrode was attached precordially and the positive (anodal) electrode to the left of the spine. Because implanted patches can interfere with a pacing current applied only along a virtual line connecting the patches, pacing thresholds also were determined with the pacing electrodes oriented horizontally across the patients' chest (right-to-left pacing), *i.e.*, approximately perpendicular to the implanted patches. For this purpose, electrodes were attached to the patients' skin in the left (negative electrode) and right (positive electrode) axillary line in the fifth intercostal space.

### MEASUREMENTS

Electrocardiogram (lead II or modified V<sub>5</sub>) and radial artery blood pressure were recorded continuously on both an oscilloscope and a multichannel recorder. Rectal temperature, serum potassium and hemoglobin concentrations, blood gas tensions, and pH were measured intermittently so as to bracket the pacing periods to ensure that threshold changes were not due to changes in these variables.

### STUDY PROTOCOL AND DETERMINATION OF PACING THRESHOLDS

Thresholds were determined during periods of hemodynamic stability and normothermia (rectal temperature greater than 36°C), approximately 30 min after induction and again at the conclusion of surgery. Thresholds were measured once in patients with patches already in place (AICD exchange). Once ventricular sensing was obtained, stimulus duration was set and remained fixed at 50 ms, whereas the pacing rate was set at 10–20 beats/min greater than the patients' prevailing heart rate. Stimulus current then was increased gradually in 10-mA increments (to a maximum of 150 mA) until ventricular capture was documented. The lowest current that resulted in consistent ventricular pacing for two respiratory cycles

was defined as the pacing threshold and then was recorded.

### STATISTICAL ANALYSIS

Data were reported as means plus or minus standard deviation and individual values. Two *a priori* null hypotheses were tested statistically. For a given pacing mode, there was no difference in pacing thresholds between patients 1) with and without implanted patches; and 2) before and after CABG (control group). These hypotheses were evaluated by the Mann-Whitney U test and the Wilcoxon test, respectively. A null hypothesis was rejected, and statistical significance was assumed at  $P < 0.05$ .

### Results

Despite patch implantation, transcutaneous pacing was possible in all patients with the electrodes in the standard anteroposterior orientation (table 1) and with a mean threshold of  $73 \pm 30$  mA. Thresholds in patients with patches ranged from 40 mA to 140 mA and were not significantly different from those in the control patients without patches before or after surgery (fig. 1). Although the presence of patches did not affect pacing thresholds in a systematic fashion, the surgical procedure *per se* significantly increased the threshold (fig. 1) from  $57 \pm 20$  mA (range: 30–90 mA) to  $94 \pm 24$  mA (range: 40–120 mA).

In contrast to pacing in the anteroposterior direction,

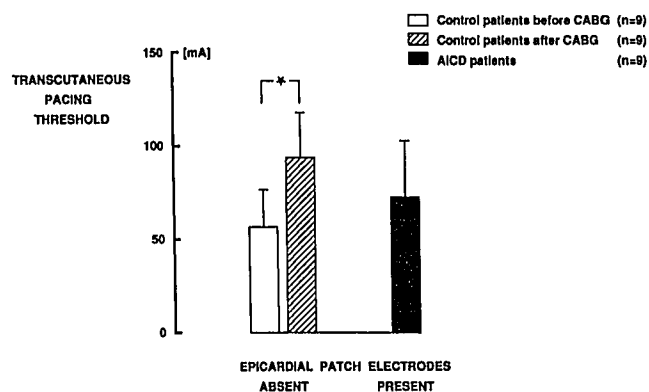


FIG. 1. Pacing thresholds for anterior-posterior transcutaneous cardiac pacing in patients with implanted epicardial patch electrodes (solid bar) compared to thresholds in control patients before (open bar) and after (hatched bar) standard coronary artery bypass graft (CABG) without patch implantation. Means  $\pm$  SD from nine patients in each group. Pacing was possible in all patients with implanted patch electrodes, and the mean  $\pm$  SD threshold ( $73 \pm 30$  mA, range 40–140 mA) was not significantly different from that in control patients before or after surgery. Cardiac surgery *per se* induced a significant increase in pacing threshold from  $57 \pm 20$  mA (range 30–90 mA) to  $94 \pm 24$  mA (range 40–120 mA). AICD = automatic implantable cardioverter defibrillator. \*Significantly different (Wilcoxon test,  $P < 0.05$ ).

successful right-to-left pacing was achieved only in a minority of patients in both groups. Pacing was possible (threshold < 150 mA) in only four patients with and one patient without patches.

Body weight (84 kg *vs.* 88 kg) and height (172 cm *vs.* 172 cm) did not differ significantly between groups (Table 1). Blood gas tensions, pH, and potassium concentrations were comparable between groups and within acceptable clinical limits at all times. No complications of pacing were noted.

### Discussion

Transcutaneous cardiac pacing was possible at normal thresholds in all patients with implanted patches and the pacing electrodes oriented in the standard anteroposterior direction. The presence of insulating electrodes sewn to the right (anterior) and left (posterior) ventricles did not impair efficacy of noninvasive transcutaneous pacing. In contrast, transcutaneous pacing in the right-to-left direction did not consistently capture the heart in patients with or without patches, and thus does not represent an acceptable alternative in patients in whom standard anteroposterior landmarks are not accessible.

These results emerged when other factors definitively or possibly affecting the pacing threshold (*e.g.*, pulse duration, skin preparation, make and size of pacing electrodes, body weight and height, core temperature, blood chemistry, surgical interventions<sup>7</sup>) were either kept constant or accounted for by design of the study.

Cardiac pacing requires that a certain threshold current reach the myocardium to capture the ventricle. No current can pass through the patches<sup>3,5,7</sup> because they are backed with an insulating material (mostly silicone rubber) and cover a sizable portion of the ventricular surfaces. We therefore hypothesized that their presence in patients with an AICD would either make transcutaneous pacing impossible or at least increase the pacing threshold.

Although to our knowledge this study is the first to evaluate the feasibility of transcutaneous pacing in patients with patches and an AICD, it appeared reasonable to suspect that the presence of patch electrodes blocks or alters the flow of current delivered to the myocardium, thus interfering with transcutaneous pacing. In fact, the presence of implanted patches almost doubled the energy required for defibrillation in dogs, with the defibrillation paddles aligned both perpendicular and parallel to the patches.<sup>3</sup> Similarly, in humans, marked difficulties to defibrillate the heart have been reported anecdotally when attempted transthoracically,<sup>4,6</sup> and even with the heart exposed using internal paddles.<sup>4</sup> The apparently conflicting results obtained with transcutaneous pacing and defibrillation, however, probably can be reconciled by the consideration that myocardial pacing requires excitation

of only a small mass of myocardium (with further propagation of excitation by the intrinsic conduction system), whereas defibrillation likely necessitates depolarization of the entire myocardium at the same time. With respect to the latter situation, patches may interfere with successful defibrillation by preventing the applied current from uniformly reaching all portions of the myocardium.

Pacing thresholds in patients with patches were not significantly different from those in patients undergoing routine CABG. Mean thresholds in patients with an AICD, however, were slightly higher compared to the control group before cardiac surgery, but slightly lower compared to the control group after surgery. This probably is due to the fact that half of the patients with an AICD underwent open-chest surgery, whereas the other half needed only an AICD (power source) exchange. Nevertheless, even in patients who underwent both AICD insertion and open-chest cardiac surgery, *i.e.*, where a maximum interference with transcutaneous pacing might be expected after chest closure, pacing was possible at thresholds similar to those of the control group (60, 70, 100, 140 mA). That cardiac surgery increases the transcutaneous pacing threshold has been reported.<sup>7</sup> Our results extend these observations by showing that, despite use of different pulse generators, pulse duration, pacing electrodes, and possibly surgical techniques, thresholds were virtually identical (approximately 98 mA *vs.* 94 mA) and increased after surgery.

In rare instances, the need may arise to pace a patient's heart transcutaneously when the anterior chest wall is not accessible for electrode positioning, such as during left anterior chest wall surgery, bilateral thoracotomy, or transverse sternotomy. By demonstrating the lack of feasibility of right-to-left pacing, which was effective only occasionally with or without patches, our results suggest that this mode does not appear to represent a clinically viable option. This is a noteworthy finding because it has been stressed that the exact posterior electrode position is not crucial for ventricular capture, even when it is moved away from the anteroposterior chest axis to the right posterior chest wall.<sup>8</sup>

Patients during or after cardiac operations, and in particular, those undergoing AICD implantation are at risk for developing bradydysrhythmias, *e.g.*, due to aggressive pharmacologic antiarrhythmic therapy, cardiac damage, or ineffectiveness of temporary epicardial pacing wires. Thus, although this study included only a small number of patients, it is reassuring that a noninvasive mode of pacing, transcutaneous pacing, applied in the standard fashion is possible even in patients with an AICD in whom implanted patches have made defibrillation difficult.

In conclusion, our results demonstrate that implanted epicardial patch electrodes sewn to the anterior right and

posterior left ventricular surface do not impair standard transcutaneous pacing or alter pacing thresholds.

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