External noninvasive temporary cardiac pacing: clinical trials


Abstract  An external cardiac pacemaker-monitor has been developed that provides safe, effective noninvasive ventricular stimulation that is well tolerated in conscious patients and allows clear recognition of electrocardiographic response. The noninvasive temporary pacemaker (NTP) has now been applied in 134 patients in five hospitals. Stimulation was tolerated well in 73 of 82 conscious patients, and nine found it intolerable. The NTP was effective in evoking electrocardiographic responses in 105 patients; the 29 failures were in the presence of prolonged hypoxia or severe discomfort. The NTP was clinically useful in 82 patients: 43 of 86 were resuscitated from emergency or expected arrest, 38 of 40 were maintained in standby readiness for up to 1 month but did not require stimulation, and one of eight patients with tachycardia obtained some clinical benefit. The NTP was especially useful in 25 patients with complications or contraindications to endocardial pacing and in 57 patients in whom insertion of an endocardial electrode was avoided. Circulation 71, No. 5, 937–944, 1985.

External noninvasive electric cardiac stimulation was introduced in 1952 as a clinically useful means of providing effective ventricular beats in emergency situations of ventricular standstill or symptomatic bradycardia. A technique for this purpose had to be simple, reliable, and quickly and easily applied. Since arrest often recurs, the technique also had to be free of invasive procedures or other significant risks. External electric stimulation did meet these requirements and was widely used for many years for ventricular standstill or bradycardia of any cause and for prevention by overdrive suppression of multifocal and repetitive ventricular beats, tachycardia, and fibrillation. External pacemakers were often prepared for emergency use by preliminary determination of the threshold for stimulation and were kept in standby readiness during periods of increased risk of arrest. Cardiac stimulation by any technique was found to be ineffective in patients in cardiac arrest due to ventricular tachycardia or fibrillation or to severely depressed myocardial excitability: it rarely aroused electrical and mechanical responses after prolonged anoxic arrest.

Cardiac stimulation with an endocardial electrode, inserted by cardiac catheterization, was introduced in 1959. Despite the considerable skill and time required for temporary electrode insertion and an incidence of complications up to 34%, endocardial pacing soon replaced noninvasive temporary cardiac stimulation because of the difficulties encountered with the earlier method, namely, discomfort in conscious patients, the obscuring of electrocardiographic responses with large stimulus artifacts or of arterial pulses with muscular contractions, and the impression that external stimulation was effective only in Stokes-Adams disease.

A modified external noninvasive temporary pacemaker-monitor was introduced in 1981. This instrument achieves temporary stimulation of the conscious patient that is usually comfortable and also allows clear recognition of cardiac responses to stimulation.

Methods  The noninvasive temporary pacemaker (NTP, ZMI Corporation, Cambridge, MA) consists of an electric cardiac pacemaker combined with a cardiac monitor and a paper recorder. The pacemaker monitor senses voltage changes of appropriate amplitude and slew rate from cardiac depolarizations or pacemaker stimuli. It provides audible and visual signals of such events with oscilloscopic and paper recordings, displays their rate, and rings an alarm if selected limits are exceeded. The pacemaker functions in the demand mode (VVI), emitting stimuli that are
synchronized to the sensed electrical signals at escape rates up to 180 beats/min and amplitudes up to 140 mA. The stimuli are of constant-current, rectilinear design, and are of 40 msec duration. Special circuitry in the monitor’s preamplifier controls the large stimulus current so that cardiac activity is clearly recognized as electrically stimulated or of intrinsic origin (figure 1).

Large stimulating electrodes of high impedance are placed on the precordium and back at the cardiac level between the left scapula and the spine and monitor leads are attached. The pacemaker output is lowered to 0 and the power is turned on. The pacemaker rate is adjusted so that the stimulus artifact falls in diastole, or at about 60/min in the presence of asystole. The pacemaker amplitude is then increased until a stimulated QRS-T response follows the artifact immediately and suppresses any intrinsic complex that might fall in its refractory period (figure 1). The stimulus amplitude is kept just above this stimulation threshold. Stimulation may be continued at any rate; in standby application it is slowed so that escape pacing appears only for bradycardia or asystole (figure 2). In emergency situations, stimulation may be started within seconds.

Safety of the NTP. The safety of external electric cardiac stimulation has been established over 30 years of extensive use. No untoward cardiac effects of external electric stimulation have been observed. Repetitive or multifocal ventricular beats, tachycardia, or fibrillation have not occurred at the rates and amplitudes of external stimulation previously available in clinical units, even in the presence of competition between an intrinsic rhythm and the artificial pacemaker, or during an acute myocardial infarction or other serious cardiac disease. In many postmortem examinations no evidence of damage to the heart or surrounding tissue resulting from the external electric impulses has been found. A recent experimental study confirmed these old observations with the absence of myocardial injury in 10 dogs subjected to 30 min of external pacing.

Before the introduction into clinical trial of this new NTP, animal studies were conducted to reexamine the risk of precipitating ventricular fibrillation. Stimuli of increasing amplitude and from 2 to 100 msec duration were applied throughout the relative refractory period in dogs with normal sinus rhythm, complete heart block, or multiple arrhythmias produced by hypoxia. Thresholds for repetitive responses, tachycardia, or fibrillation were five to 16 times the thresholds for single responses. Such ratios far exceed the maximum output of the NTP. Moreover, pacing in the demand mode further increases the threshold for repetitive responses. In addition, for sake of comfort, clinical stimulation is adjusted to levels just above threshold for single responses. Therefore, stimulation with the NTP was considered safe with respect to the risk of producing repetitive responses, and clinical trials were undertaken.

Clinical trials. The NTP was used in five centers by investigators (emergency department physicians or cardiologists) experienced in cardiac resuscitation. If feasible, the NTP was applied when temporary ventricular stimulation or its immediate availability was required. It was often applied instead of endocardial pacing or in the interval before it could be established. The NTP was used to arouse, accelerate, or maintain the ventricular rate in the emergency of cardiac arrest resulting from ventricular asystole or bradycardia with pulseless or hypotensive collapse. The NTP was placed on standby in patients with disturbances in rhythmlicity or conduction during the course of anesthesia, acute myocardial infarction, cardiac drug toxicity, electrolyte imbalance, or complications after implanted pacemaker procedures. The NTP was also used in attempts to terminate, suppress, or provoke some tachyarrhythmias.

Results

Patients. The NTP was used in 134 patients in the emergency department, cardiac special care units, and in the wards of the Beth Israel, Boston City, and Brigham and Women’s Hospitals in Boston; the Hennepin County Medical Center in Minneapolis; and the York Hospital in York, PA. The numbers of cases, conditions of the patients, circumstances leading to use, and results varied considerably among the five institutions.

The ages of the 134 patients ranged from 29 to 95 years, with an average of 70 years; 87 were men and 47 were women. The diagnoses and indications for noninvasive temporary pacing are listed in table 1.

Four categories of use were identified: emergency arrest, expected arrest, standby, and tachycardia. (1) The emergency arrest group comprised 60 patients in whom the NTP was applied and used during asystolic

FIGURE 2. Demand stimulation after 1.2 sec escape intervals in a patient with repeated syncope from atrial fibrillation and high-degree atrioventricular block.
TABLE 1
Diagnoses and indications for noninvasive temporary pacing (n)

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients with acute myocardial infarction</td>
<td>25</td>
</tr>
<tr>
<td>Symptomatic bradycardia or asystole</td>
<td>23</td>
</tr>
<tr>
<td>AV block</td>
<td>11</td>
</tr>
<tr>
<td>Sinus node dysfunction</td>
<td>12</td>
</tr>
<tr>
<td>Bradycardia or asystole after defibrillation</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>101</td>
</tr>
<tr>
<td>Patients without acute myocardial infarction</td>
<td></td>
</tr>
<tr>
<td>Symptomatic bradycardia or asystole</td>
<td>100</td>
</tr>
<tr>
<td>AV block</td>
<td>25</td>
</tr>
<tr>
<td>Sinus node dysfunction</td>
<td>14</td>
</tr>
<tr>
<td>Bradycardia or asystole after defibrillation</td>
<td></td>
</tr>
<tr>
<td>or tachycardia</td>
<td></td>
</tr>
<tr>
<td>Drug toxicity (digoxin, verapamil)</td>
<td>10</td>
</tr>
<tr>
<td>Implanted pacemaker failure or infection</td>
<td>8</td>
</tr>
<tr>
<td>Implanted pacemaker procedures, cardioversions</td>
<td>27</td>
</tr>
<tr>
<td>Anesthesia</td>
<td>8</td>
</tr>
<tr>
<td>Other: vagal reflex; hyperkalemia, cardiac catheterization, and angiography; tricuspid valve prosthesis; terminal cardiac, renal, pulmonary, cerebral, or malignant disease</td>
<td>36</td>
</tr>
<tr>
<td>Torsades de pointes</td>
<td>2</td>
</tr>
<tr>
<td>Atrial or ventricular tachycardias</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>134a</td>
</tr>
</tbody>
</table>

AV = atrioventricular.
aMultiple conditions, e.g., AV block, are present in many cases.

arrest or bradycardia with pulseless or hypotensive collapse. (2) In the expected arrest group the NTP was tested and kept in emergency readiness for use because disturbances in conduction or rhythmicity suggested the likelihood of imminent asystole, bradycardia, or tachycardia. In 26 patients arrest or symptomatic bradycardia did occur, and the immediately available cardiac stimulation was applied as needed. (3) In the standby category of 40 patients, the NTP was tested and maintained in emergency readiness, often for long intervals, but was never needed in treatment. (4) In the tachycardia group of eight patients stimulation was applied in attempts to terminate or provoke atrial and ventricular tachyarrhythmias.

Stimulation thresholds and comfort. The stimulation threshold is the current required to evoke an electrical ventricular response. With such a response, stimulation was considered to be technically effective — whether or not it was hemodynamically effective or clinically useful. Stimulation thresholds ranged from 20 to 140 mA, but were usually between 40 and 70 mA.

The sensations with stimulation were described as “comfortable” (from a mild pectoral twitch to a moderate thump), “tolerable” (a strong thump), and “intolerable” (a severe thump or an intense burning or stinging pain that required termination of stimulation). Unconscious patients often showed strong skeletal muscle contractions but no discomfort. The only additional usual reaction to stimulation was mild, transient, and painless erythema under the electrodes.

The correlations of stimulation thresholds with levels of comfort in the four categories of use are shown in Table 2. Most patients tolerated external stimulation well. It was intolerable in only nine patients, three of whom were obviously very apprehensive. Three more had the stinging or burning characteristic of cutaneous nerve stimulation. Two of these patients had small cuts or abrasions on the precordium. Repositioning of the electrode over intact skin in one instance removed the sting and permitted effective comfortable stimulation. Placement of the posterior electrode over the spine or scapula increased the stimulation threshold and discomfort in several instances.

Discomfort was related to the intensity of muscular contractions and therefore to stimulus amplitude. Some patients with pulmonary emphysema or heavy thoracic musculature had high thresholds for stimulation and greater discomfort. Conversely, many elderly patients with thin chest walls were easily and comfortably stimulated at amplitudes below 45 mA. Obesity and large body size were not clearly associated with high thresholds. Hypoxia, manifested by unconsciousness in 52 patients, was related to high thresholds — over 80 mA in 12 patients and over 140 mA, the maximum output of the NTP, in 25 more.

Apprehension was also important to the degree of discomfort. Initial “pain” often diminished as the patients became accustomed to the procedure and their apprehension receded.

Stimulation effectiveness. Noninvasive pacing was technically effective in producing electrical ventricular responses in 105 of the 134 patients in whom it was applied. Table 3 shows the technical effectiveness and clinical usefulness of stimulation and data on in-hospital survival in the four categories of use.

Stimulation was ineffective in 29 patients, including 25 unconscious ones in arrest, three with intolerable discomfort in whom sufficient stimulation could not be applied, and one who was stimulated only during bursts of irregular ventricular tachycardia.

Clinical usefulness of the NTP. Effective stimulation, clinical usefulness, and survival were usually directly related. In the two groups of emergency and expected arrest, the NTP was considered clinically useful if the patient was resuscitated from arrest; in the standby and tachycardia groups, usefulness was determined based on other clinical benefits. In the 105 patients in whom stimulation was effective, it was clinically useful in 82:
in 43 patients who were resuscitated from arrest (20 from emergency and 23 from expected arrest); in 38 patients on standby in whom endocardial pacing was avoided, delayed, contraindicated, or had produced complications; and in one patient in the tachycardia group in whom the risk of recurrent ventricular tachycardia was tested.

In a representative case, a patient with digitalis toxicity was resuscitated from the emergency arrest of pulseless bradycardia after bursts of torsades de pointes. She was then maintained fully conscious and comfortable in regular, hemodynamically effective, paced rhythm for 100 min during placement of a temporary endocardial system (figure 3).

Nine patients were successfully resuscitated with the NTP, but died later of recurrent arrest, cerebral hemorrhage, acute myocardial infarction, or other terminal diseases (renal, pulmonary, or malignant).

Stimulation was not clinically useful in 52 patients: in the 29 patients in whom stimulation was ineffective, in 17 of 19 patients with terminal circulatory collapse or electromechanical dissociation in the two arrest groups, and in six of the seven patients in the tachycardia group in whom stimulation was also effective. (One patient in the tachycardia group is already counted among the 29 with ineffective stimulation.) Five patients in whom external or endocardial pacing was not useful were saved by other continuing measures, such as full cardiopulmonary resuscitation with fluid, electrolyte, and drug therapy.

The NTP was tested and kept in readiness but was never used in treatment in 40 patients in the standby category. Six patients were undergoing anesthesia, 24 were undergoing pacemaker procedures, five had acute myocardial infarction and atrioventricular or bundle branch block, and five had bradycardia, digoxin toxicity, or ventricular tachycardia. In five patients the NTP was kept in standby readiness for long intervals (from 5 days to 1 month).

In the tachycardia group a brief attempt was made to terminate atrial and ventricular tachycardias with bursts of rapid external ventricular stimulation. In four patients with atrial flutter and in two patients with atrial tachycardia, stimulation was effective but clini-

### TABLE 2
Stimulation threshold and comfort levels in the four categories of use

<table>
<thead>
<tr>
<th>Threshold (mA)</th>
<th>Emergency arrest (n = 60)</th>
<th>Expected arrest (n = 26)</th>
<th>Standby (n = 40)</th>
<th>Tachycardia (n = 8)</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U</td>
<td>C</td>
<td>T</td>
<td>I</td>
<td>U</td>
</tr>
<tr>
<td>&lt;46</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>46-60</td>
<td>6</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>61-80</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>1^</td>
<td>0</td>
</tr>
<tr>
<td>81-100</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>101-140</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>&gt;140^</td>
<td>24^</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1^</td>
</tr>
<tr>
<td>?</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>46</td>
<td>11</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

U = unconscious; T = tolerable; I = intolerable; C = comfortable; ? = not recorded.

^Ineffective (total number = 29).

### TABLE 3
Stimulation effectiveness, clinical usefulness of NTP, and survival in the hospital

<table>
<thead>
<tr>
<th>QRS response</th>
<th>Emergency arrest (n = 60)</th>
<th>Expected arrest (n = 26)</th>
<th>Standby (n = 40)</th>
<th>Tachycardia (n = 8)</th>
<th>Total (134)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>35</td>
<td>25</td>
<td>38</td>
<td>7</td>
<td>105</td>
</tr>
<tr>
<td>No</td>
<td>25</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>29</td>
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</table>

<table>
<thead>
<tr>
<th>Clinically useful</th>
<th>Emergency arrest (n = 60)</th>
<th>Expected arrest (n = 26)</th>
<th>Standby (n = 40)</th>
<th>Tachycardia (n = 8)</th>
<th>Total (134)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>20</td>
<td>23</td>
<td>38</td>
<td>1</td>
<td>82</td>
</tr>
<tr>
<td>No</td>
<td>40</td>
<td>3</td>
<td>2</td>
<td>7</td>
<td>52</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Emergency arrest (n = 60)</th>
<th>Expected arrest (n = 26)</th>
<th>Standby (n = 40)</th>
<th>Tachycardia (n = 8)</th>
<th>Total (134)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>15</td>
<td>23</td>
<td>38</td>
<td>7</td>
<td>83</td>
</tr>
<tr>
<td>No</td>
<td>45</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>51</td>
</tr>
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</table>
cally useless. The patient with irregular ventricular tachycardia who was stimulated only during tachycardia is also listed as a failure in this group. A second patient with paroxysmal ventricular tachycardia and acute myocardial infarction was stimulated to test the adequacy of his antiarrhythmic drug program. The first effective stimulus evoked the typical tachycardia. Thus, this case is listed as the only clinically useful stimulation in this group because valuable clinical information was obtained.

**Duration of arrest.** The effectiveness of stimulation, its clinical usefulness, and the final outcome were examined in relation to the duration of preceding arrest or hypoxia (table 4). Among the 60 patients in the category of emergency arrest the duration of the arrest was "brief" (less than 5 min) in 13 conscious patients and in

<table>
<thead>
<tr>
<th>TABLE 4</th>
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<tr>
<td>Effect of duration of arrest on stimulation effectiveness, clinical usefulness (resuscitation), and survival in emergency and expected arrest categories</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Emergency arrest (n = 60)</th>
<th>Expected arrest (n = 26)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>QRS response</td>
<td>Brief (n = 16) Prolonged (n = 44) All emergencies (n = 60)</td>
<td>Brief (n = 24) Prolonged (n = 2) All expected (n = 26) Total arrests (n = 86)</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>15 20 35</td>
<td>23 2 25</td>
<td>60</td>
</tr>
<tr>
<td>No</td>
<td>1 24 25</td>
<td>1 0 1</td>
<td>26</td>
</tr>
<tr>
<td>Resuscitation</td>
<td></td>
<td></td>
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<td>22 1 23</td>
<td>43</td>
</tr>
<tr>
<td>No</td>
<td>4 36 40</td>
<td>2 1 3</td>
<td>43</td>
</tr>
<tr>
<td>Survival</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>11 4 15</td>
<td>23 0 23</td>
<td>38</td>
</tr>
<tr>
<td>No</td>
<td>5 40 45</td>
<td>1 2 3</td>
<td>48</td>
</tr>
</tbody>
</table>
three unconscious ones with witnessed arrest (table 4). Stimulation was effective in 15 patients and ineffective in one in whom it was stopped because of intolerable discomfort. Resuscitation was successful in 12, but four subsequently died with recurrent ventricular fibrillation, circulatory collapse, or cerebral hemorrhage. In three patients in whom stimulation was effective but not clinically useful, only electromechanical dissociation ensued. Eleven patients survived: eight were resuscitated with the NTP and three responded to vigorous fluid, electrolyte, and drug therapy.

In the remaining 44 patients in the emergency arrest group, hypoxia or arrest was “prolonged” for 5 to 30 min. External stimulation was effective in 20 of these most difficult cases: resuscitation was successful in eight but four died later and effective stimulation produced electromechanical dissociation without resuscitation in 12. The remaining 24 patients showed no response to stimulation and also died.

In contrast, under the conditions of standby readiness in the 26 patients in the expected arrest group, stimulation was usually prompt (24 patients), technically effective (25 patients), and clinically useful, i.e., resuscitation was successful (23 patients), and 23 patients survived. Of the three patients in whom stimulation was ineffective or in whom there was lack of clinical benefit, two suffered prolonged hypoxia. The three fatalities were in patients with terminal myocardial, pulmonary, or renal disease and occurred late (well after initial resuscitation in two).

Among the 86 patients with arrest (table 4) the NTP was technically effective in 60 and was of clinical benefit (successful resuscitation) in 43 (20 in emergency and 23 in expected arrest); 38 patients survived.

**NTP and temporary endocardial pacing**

**Comparisons of hemodynamic effects.** Temporary external noninvasive and temporary endocardial pacing were used sequentially in 24 patients. In 21 instances hemodynamic responses to stimulation by the two methods were similar. In 13 patients emergency resuscitation by external stimulation was followed by unhurried institution of temporary endocardial pacing; in four effective endocardial pacing was replaced by external stimulation because of infected electrodes, overly long maintenance of an endocardial electrode, or terminal coma; in two initial endocardial and subsequent external stimulation failed equally to restore circulation; and in two patients initially successful endocardial pacing became ineffective and external stimulation was successfully substituted. Hemodynamic comparisons were not possible in three patients with serious complications related to endocardial pacing (ventricular fibrillation or asystole), but external pacing was effective and instituted without difficulty.

**Contraindications to endocardial pacing.** Tricuspid valve prostheses, hemorrhagic states, digoxin toxicity with recurrent ventricular tachycardia, an infected permanent endocardial electrode, aspiration pneumonia, delayed special legal consent, and bone marrow suppression from chemotherapy prevented or delayed the invasive placement of an endocardial electrode in each of nine patients with atioventricular block or sinoatrial depression who suffered recurrent ventricular asystole or tachycardia. The NTP provided standby protection and actual pacing for a period of from a few hours during a myocardial electrode implantation in the patient with a tricuspid valve prosthesis to 1 month in the patient undergoing chemotherapy.

**Complications of endocardial pacing.** In eight patients complications of endocardial stimulation produced clinical difficulties that were usually resolved with the NTP. In two patients the endocardial electrode could not be placed successfully, so the NTP was used instead. After resuscitation with the NTP in a third patient, a subsequent attempt to pass an endocardial electrode failed and ended in a fatal arrest. In two patients initially effective temporary endocardial pacing became unreliable, whereupon stimulation promptly restored effective rhythm. In two patients endocardial pacing produced ventricular fibrillation that was followed by defibrillation and asystole; external stimulation resuscitated the patients without arrhythmia. In a final patient with acute myocardial infarction and atioventricular block, an infected temporary endocardial electrode led to septicemia. Application of the NTP in the standby mode permitted removal of the electrode and the septicemia abated.1

**Avoidance of endocardial electrode placement.** The prior application of the NTP made unnecessary the invasive placement of an endocardial electrode in 57 patients, two in emergency arrest, 18 in expected arrest, and 34 in standby readiness in preparation for arrest. The conditions under which external temporary pacing was applied included temporary or long-term pacemaker procedures or problems, acute myocardial infarction, drug toxicity (digoxin, verapamil), anesthesia (some for cardioversion), vagal reflexes, tricuspid valve prostheses, hyperkalemia, and prolonged hypoxia associated with atioventricular or intraventricular block, sinoatrial depression, or unidentified arrest, bradycardia, or syncope (table 1).

**Discussion**

These experiences in 134 patients establish the safety, efficacy, and clinical usefulness of this new nonin-
vasive temporary pacemaker. The NTP is quickly and easily applied in standby readiness and in the emergency of cardiac arrest. It stimulates effective ventricular beats, when the heart is capable of responding, without the complications of an invasive procedure; electrocardiographic responses are clearly recognized; and it is well tolerated by most conscious patients.

Modifications in the electrodes have largely eliminated the stinging or burning pain from stimulation of cutaneous nerves that previously rendered external stimulation intolerable at about 20 mA. Intolerable stinging pain was described by only three patients, two of whom showed minor skin injury under the anterior electrode. Relocation of the electrode over intact skin eliminated the sting and permitted comfortable stimulation in one of these. Shaving or applying and removing sensing electrodes may damage the skin or leave salt deposits, with resulting areas of high electron density that produce sting during stimulation. When time permits, the skin should be examined to avoid traumatized areas and washed to remove salt.

A second type of discomfort resulting from contraction of local skeletal muscles was primarily related to current amplitude. Modifications of the stimulus duration and shape have reduced the threshold for stimulation to a usual range of 40 to 70 mA. Skeletal contractions were thereby diminished and were usually well tolerated. Although occasionally uncomfortable, they infrequently required termination of stimulation. In several instances, misplacement of the back electrode over bone or at a level other than that of the anterior electrode increased the threshold for stimulation and consequently the muscular contractions. Apprehension, which often increased discomfort, was usually allayed by explanation of the procedure and by increasing amplitude gradually. Occasionally, rapidly acting analgesic or tranquilizing agents were used with benefit. Thus, external cardiac stimulation has been comfortably continued for prolonged intervals up to 25 hr and intermittently up to 17 days in conscious patients.

The precipitation of ventricular tachycardia or fibrillation by external pacing had been a serious, long-standing concern. In these clinical trials, repetitive ventricular responses, tachycardia, or fibrillation were not observed with use of the NTP, even in patients in whom acute myocardial infarction or endocardial pacing had just produced these arrhythmias. The usual stimulation at currents just above threshold for single response, together with the demand mode of stimulation, appear to have been effective in preventing these ventricular arrhythmias, even in high-risk patients.

External noninvasive stimulation has often proved an advantageous alternative to temporary transvenous endocardial pacing. It can be applied more quickly and easily and for as long and as often as needed. In patients with contraindications to, or delays, failures, or complications associated with temporary endocardial pacing, the NTP may be the only effective modality available. Under the urgent and often hectic circumstances of cardiac arrest, endocardial electrode placement is much too slow and too difficult, often interfering with other resuscitative procedures. Noninvasive temporary pacing has been of great clinical benefit, resulting in resuscitation from arrest in 43 cases. Even under the most difficult circumstances of prolonged emergency arrest eight patients were resuscitated and four survived.

The invasive, time-consuming, and expensive procedure of temporary endocardial electrode insertion was avoided in 57 patients in whom temporary stimulation or its prompt availability was provided by the NTP. The ease and safety of noninvasive stimulation encouraged application of the NTP in standby readiness in very ill, weak, or unstable patients (such as those with acute myocardial infarction) when borderline indications for temporary pacing existed, or when endocardial pacing failed, was contraindicated, delayed, or caused complications.

Endocardial electrodes placed prophylactically are often not actually used for pacing. Without the NTP in standby readiness, many pacemaker-dependent patients requiring long-term pacemaker procedures would have had to undergo preliminary temporary electrode placement in addition.

Prolonged cardiac monitoring with the external pacemaker in standby emergency readiness for intervals of up to 1 month was easily accomplished. In contrast, temporary endocardial electrodes are usually removed or replaced within 5 days because of concern about displacement or infection.

The observations in our 24 patients who were stimulated both externally and with endocardial electrodes in close sequence show their hemodynamic effects to be similar. The electrical and contractile responses of the heart and the hemodynamic and clinical effects of stimulation depend on the condition of the heart and the circulation, not the location of the stimulating electrodes.

An electrical response may be evoked only if the myocardium is still excitable and is stimulated in the recovery phase of the cardiac cycle. The progression to effective beats, full resuscitation, and recovery, or to electromechanical dissociation or circulatory collapse and death, depends on myocardial contractility, the
duration and depth of cardiac and cerebral hypoxia, and other factors. Patients in our series have shown all stages of these sequences, and the many fatalities underscore the extent of hypoxic damage and severe underlying disease. High thresholds for stimulation in 12 unconscious patients and the ineffective stimulation at maximum output in 25 more indicate decreasing excitability of the heart and of the brain during the hypoxia of cardiac arrest. The NTP can only provide the first step of appropriate stimulation, given quickly and safely.

The cases of 19 patients showing electrical responses to stimulation but no observable pulse or blood pressure indicate residual partial myocardial function with electrical responsiveness but loss of myocardial contractility (electromechanical dissociation) or circulatory collapse. The ultimate resuscitation and survival of five such patients indicate that effective myocardial contractility and circulation may be restored even at this stage. These observations raise the hope that better results may come with efforts to start resuscitation and to apply stimulation earlier in the course of cardiac arrest.

Placement of temporary endocardial electrodes, of course, provides many capabilities that are not possible with external noninvasive pacing. Many electrophysiologic studies, recording of endocardial electrograms, and identification and termination of atrial and ventricular tachyarrhythmias are outside the domain in which external temporary pacing is now useful.

So far, the clinical testing in this series has been concerned with use of the NTP under emergency or urgent circumstances. Noninvasive temporary cardiac stimulation may, however, prove useful in many elective nonemergency situations. It may well be applied for termination as well as suppression of ventricular tachycardia. Despite our few negative experiences in this study, atrial tachycardia may also be interrupted and terminated by application of properly timed stimuli in patients with retrograde conduction. Noninvasive precipitation of ventricular tachycardia with sequential extrastimuli to evaluate antiarrhythmic drug schedules is another potential use for the technique. Noninvasive evaluation of postextrasystolic potentiation may be performed more readily, comfortably, and repeatedly with external mechanical stimulation of the heart. Other electrophysiologic and pharmacologic studies in which this noninvasive technique could be used come readily to mind, including measurement of effects of cardioactive drugs on the refractory period as a measure of drug effect, posttachycardia suppression of rhythmicity, and noninvasive stress testing with periods of controlled tachycardia in the recumbent patient.

This extensive experience with 134 patients treated by several investigators in five institutions under various circumstances confirms the safety and efficacy of this new technique of noninvasive temporary pacing. The NTP provides a quickly and easily applied, simple, and safe means of temporary, effective ventricular stimulation, even in conscious patients. Its external, noninvasive application permits immediate and repeated use for long intervals without the delays, difficulties, or complications related to insertion of an endocardial electrode. In buying time for the subsequent placement of a temporary endocardial electrode or in avoiding that procedure altogether, in emergency resuscitation from bradycardia or asystole, in suppression of ventricular tachycardia, and in standby monitoring in emergency readiness for pacing when bradycardia or asystole appears likely, the NTP has proved of major clinical benefit.

References
