Noninvasive Temporary Cardiac Pacing

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ZOLL PM: Noninvasive temporary cardiac pacing. External noninvasive temporary cardiac pacing has been developed as a feasible technique with resolution of many of the earlier problems including thresholds for pacing, cutaneous nerve pain, and skeletal muscle contraction. At a stimulus duration of 40 msec, the threshold for cardiac response is reduced, which significantly lowers the extent and severity of muscle contractions. With experience in thousands of patients, noninvasive temporary pacing has been proven to be both safe and effective. (J Electrophysiol, Vol. 1, 1987)

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Electrical stimulation of the heart was introduced into clinical use in 1952 as an external technique. Noninvasive means of resuscitating the heart from ventricular asystole or symptomatic bradycardia. Any procedure used in the emergency of standstill or bradycardia must permit quick and easy application, must be reliable, and must be safe. Noninvasive temporary cardiac pacing met these stringent requirements. This technique was widely used for many years in emergency situations to stimulate ventricular beats and to prevent ventricular tachycardia and fibrillation by overdrive suppression. In nonemergency situations, noninvasive pacemakers were often prepared in standby readiness when impending arrest was feared.

The large electric stimuli required for noninvasive cardiac stimulation usually produced sharp burning or stinging pain in the skin and strong contractions of skeletal muscles. This discomfort, often intolerable, restricted external stimulation to use in unconscious patients or to brief use in desperate situations. In addition, cardiac responses were often unrecognizable because the large stimuli distorted the electrocardiograms and the muscular contractions obscured arterial pulsations.

Cardiac stimulation was found to be ineffective during ventricular tachycardia or fibrillation. It is also ineffective in the presence of severe depression of myocardial excitability and contractility. After prolonged arrest (four minutes or more), stimulation is rarely lifesaving; usually it produces no cardiac response at all; occasionally it provokes brief episodes of clinically useless electromechanical dissociation. Late in arrest that was caused initially by ventricular fibrillation, when the fibrillatory waves have died out and the electrocardiogram shows a straight line, stimulation of the anoxic heart is futile.

Many early papers reported successful resuscitation in unexpected arrest of varying etiology. Nonetheless, the many failures late in arrest, together with the difficulty in recognizing cardiac responses, led to the erroneous impression that external stimulation was effective only in Stokes-Adams disease (i.e., in the presence of high-degree AV block), even that external stimulation was not effective at all.

Invasive Temporary Pacing

A substantially different, invasive, transthoracic technique for emergency cardiac pacing was introduced in 1958. This technique, a
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Noninvasive Temporary Mechanical Pacing

provided mechanical impulses that stimulated atrial or ventricular beats. It was used successfully in over 100 subjects, for the arousal or acceleration of the heart in ventricular standstill or bradycardia, for the termination of atrial and ventricular tachycardias, and mostly for the arousal of ectopic ventricular beats on demand in noninvasive studies of postextrasystolic potentiation. Although better tolerated than noninvasive electric stimulation, the mechanical stimuli were usually too painful for prolonged use, and the technique was finally abandoned.

Modified Noninvasive Temporary Pacemaker-Monitor (NTP)*

In response to the difficulties with previous noninvasive and invasive methods of cardiac stimulation, a modified technique of external noninvasive temporary electric cardiac pacing was introduced in 1981. The effects of variations of the stimulus and of the electrodes on the thresholds for cardiac response, for cutaneous sensory nerve pain, and for skeletal muscle contraction were examined. Strength duration curves for stimulation of skeletal and cardiac muscle were found to differ significantly in that skeletal muscle is stimulated maximally with electric pulses less than 1 msec long, whereas the threshold for cardiac muscle continues to drop with pulses longer than 5 msec. With stimuli of 40 msec, the threshold for cardiac responses is reduced, usually to 35 to 70 mA. These low currents together with their constant-current shape (relatively uniform current amplitude without current spikes that preferentially stimulate skeletal muscle) greatly reduce the extent and severity of muscle contractions.

The threshold for cutaneous nerve pain is a function of current density (mA/cm²). The threshold is not reached and the skin pain is eliminated by using large electrodes with nonmetallic inner surfaces that transmit the stimuli of relatively low and uniform current density across the skin without "hot spots" of localized high intensity.

*Noninvasive Temporary Pacemaker. ZMI Corporation, Cambridge, MA.
In addition, the NTP contains a specially designed monitor that provides full monitoring, alarm, and demand functions. The monitor controls the large, prolonged stimulus signal by inactivating the amplifier circuitry for 80 msec to prevent saturation. The monitor also presents a clearly recognizable, unique symbol of the stimulus artifact that precisely marks the time of stimulation. These innovations promote ready identification of both stimulated and intrinsic beats (Fig. 1).

Safety of the Noninvasive Temporary Pacemaker

Another prevalent misconception was that stimuli longer than 5 msec increase the risk of ventricular fibrillation. Since the NTP uses a stimulus duration of 40 msec, the relation of stimulus duration to the risk of producing repetitive responses, tachycardia, or fibrillation was examined in animals before the NTP was applied to patients. With stimuli 5 to 100 msec long, the thresholds for repetitive responses, tachycardia, or fibrillation were found to be 5 to 16 times the thresholds for single responses. Such high thresholds far exceed the maximum output of the clinical, modified noninvasive pacemaker.\textsuperscript{16} In a similar study in six normal dogs, Voorhees confirmed these results, finding the “safety factor” to average 12.6, but never to be less than 7.\textsuperscript{18} Thus, the NTP is incapable of delivering a stimulus of sufficient amplitude to provoke repetitive responses, tachycardia, or fibrillation. Furthermore, for the sake of comfort in clinical situations, the stimulus amplitude is adjusted to just above pacing threshold for that individual—again, far below the threshold for fibrillation. In this regard, noninvasive pacing is much safer than invasive endocardial pacing in which the pacing threshold may be so low that the pulse generator routinely provides stimuli well over five times the pacing threshold. Indeed, the placement of the endocardial electrode itself carries a significant risk of provoking ventricular fibrillation by mechanical stimulation, even before pacing is started.

Clinical experience with noninvasive pacing has confirmed its safety. No untoward cardiac effects have been documented since its introduction in 1952, even in the presence of competition between the artificial pacemaker and intrinsic rhythm, or during acute myocardial infarction. The NTP has now been used in thousands of patients: clinical experience has been accumulating, and many clinical trials are being reported in varied clinical settings.\textsuperscript{19-22} As would be expected in desperate clinical situations, ventricular tachycardia and fibrillation have occasionally occurred. In only one instance, however, was tachycardia precipitated by a stimulus: in a terminally ill patient with recurrent ventricular tachycardia, a paroxysm was \textit{deliberately} provoked to evaluate a toxic, antiarrhythmic drug regimen.\textsuperscript{79}

In our large clinical study of the NTP,\textsuperscript{19} 11 patients who were undergoing either myocardial infarction or endocardial pacing suffered ventricular tachycardia or fibrillation that required countershock. Noninvasive pacing was...
Comfort and Effectiveness of Noninvasive Temporary Pacing

Effective stimulation signifies only the excitation of a cardiac depolarization. Whether a cardiac contraction follows depends on the state of electromechanical coupling in the myocardium. Stimulation with the NTP is usually effective and usually comfortable or tolerable for most conscious subjects (about 90%) at threshold levels between 40 and 70 mA. Thresholds as low as 20 mA have rarely been observed, but levels up to and above the maximum of 140 mA are often present when cardiac excitability has been depressed. Intolerable discomfort may also infrequently prevent effective stimulation even at low levels, in some instances from severe skin pain at the site of small nicks or abrasions of the skin under the electrodes. Intolerance, also caused by severe apprehension, may be relieved by small intravenous doses of morphine, meperidine, or diazepam, as is often done during cardiac catheterization. Strong muscular contractions may be tolerable for brief periods, but they may become intolerable with prolonged or rapid stimulation. Pulmonary emphysema and large pectoral muscles may lead to high thresholds for stimulation and strong, painful contractions. Obesity and large body size are not clearly associated with high thresholds; on the other hand, many frail patients with thin chest walls are comfortably stimulated at thresholds below 45 mA.

Hemodynamic Responses to Noninvasive Temporary Pacing

Clinical observations from 1952 to the present have demonstrated hemodynamically effective responses to noninvasive pacing in literally thousands of subjects, with many resuscitations from arrest and restorations of effective circulation. Comparisons of sequentially applied endocardial and noninvasive temporary pacing in 21 patients showed the hemodynamic responses to be similar. A detailed hemodynamic study of 16 patients who underwent endocardial and then noninvasive pacing during cardiac catheterization again showed equivalent hemodynamic responses to both pacing techniques. Incidentally, noninvasive pacing initially stimulates the right ventricle, as does right ventricular endocardial pacing. The electrical and mechanical responses of the heart and, therefore, the hemodynamic and clinical effects of stimulation depend on the condition of the heart and the circulatory system. The effects also depend on the heart rate and atrioventricular sequence. They do not depend, however, on whether pacing is endocardial or external.

Clinical Application of Noninvasive Temporary Pacing

The NTP has now been applied successfully in all the conditions for which temporary pacing has been used: in the emergency of asystolic arrest or symptomatic bradycardia; in overdrive suppression or termination of repetitive ventricular ectopy, tachycardia, and fibrillation; and in standby readiness during periods of increased risk of arrest. Asystole and bradycardia generally result from depression of the sinoatrial node or from AV block. Such depression of rhythmicity and conduction may be caused by many factors or combinations of factors. Known conditions include myocardial infarction, either acute or old; sinus node dysfunction ("sick sinus syndrome"); reflex vagal depression from hypersensitive carotid sinus or gastrointestinal reflexes often associated with nausea or vomiting (often induced by drugs, particularly chemotherapy for malignancy); toxicity of cardioactive drugs (digoxin, verapamil, quinidine, lidocaine, beta-blocking agents); hyperkalemia; countershock for atrial or ventricular fibrillation or tachycardia; Stokes-Adams disease; failure of long-term cardiac pacemakers; procedures to implant, revise, or replace pacemakers; anesthesia, especially in patients with impaired rhythmicity or conduction; and cardiac catheterization, angiography, and angioplasty. The special features of noninvasive pacing —
avoided in 57 patients by use of the noninvasive temporary pacemaker—a significant clinical benefit. The easy, comfortable application of the NTP encouraged its use in unstable patients with borderline indications. These patients clearly benefited from the extended protection.

Additional applications of the NTP are now being tested that exploit the capability of safe, comfortable, noninvasive, ventricular stimulation on demand in conscious patients. Rapid, timed stimulation with specially designed noninvasive pacemakers has been successful in terminating atrial and ventricular tachycardias in a few instances. Tachycardia induced by controlled noninvasive pacing has been used successfully as a stress test in a series of 16 patients. Unfortunately, the discomfort from pectoral muscle contractions is increased with rapid stimulation, so that about one-third of the patients experienced significant discomfort. Other applications include studies of postextrasystolic potentiation, the effects of cardiac drugs on the refractory period, and the suppression of rhythmicity after tachycardia. These uses of the noninvasive temporary cardiac pacemaker require further exploration.

Thus, the NTP was developed as a logical extension of the original external cardiac pacemaker. It has solved the problems of severe discomfort and questionable effectiveness. It is a safe, usually tolerable, and effective method of ventricular stimulation. Being noninvasive, it is quicker, easier, more certain, and safer than endocardial stimulation. Therefore, it is the method of choice for current and future applications of temporary ventricular pacing.

References

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