The Pacemaker Story: A Cold Heart Spinoff*

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It is 1949. Room 64 in the basement of the Banting Institute in Toronto was the home of the fledgling cardiovascular surgical laboratory. Experiments on the microcirculation and on hypothermia were initiated as two different projects. We were astonished to find as work progressed, that they were closely interrelated: Cooling an animal below a certain body temperature level produced serious obstructions to flow in the capillary circulation. Furthermore, the excitement of work in hypothermia was overshadowed by a great cloud of frustration: When the laboratory animal was cooled below 24°C, the heart would arrest—and yet infant animals could be safely cooled and resuscitated from body temperatures near freezing (5°C). We were in a hurry to solve these problems so that we could study deep hypothermia, which we hoped would allow direct vision correction of heart defects. Why did the cold heart suddenly stop? We pondered, discussed, and researched the subject, but three years passed without an answer.

One morning, a standard experiment was planned. As I entered the laboratory, an anesthetized dog was already being cooled in refrigeration blankets with ice bags. At a body temperature of 22°C, with regular heart action and adequate blood pressure, the cooling was discontinued, the top blanket removed, and the chest opened. Cardiac arrest was not expected to occur until 20°C, so the pericardium was opened. We were now ready to make certain physiologic observations regarding hypothermia, after which the pericardium and chest would be closed and the animal rewarmed.

Just as we were about to begin these tests, the heart unexpectedly stopped and lay quietly in standstill. Cardiac massage did not restart it. In some frustration and desperation, since the experiment would have to be postponed, I gave the left ventricle a good poke with the forceps I was holding. There was an immediate and strong contraction that involved all chambers—and then it returned to standstill. I did it again with the same result and marvelled at the unexpected observation. I poked it regularly every second. It resembled a normal beating heart. The technician/anesthetist said, "Hey, I am getting a blood pressure here." Not only were these real contractions that I induced, but the heart was forcibly expelling blood into the circulation. Our experimental animal was successfully resuscitated by maintaining heart action in this manner and with manual cardiac massage while it was being rewarmed, and it later recovered completely.

We had now found a project to be pursued with vigor. The heart had stopped while it appeared to be perfectly capable of continued function. Perhaps an electrical impulse had the same effect as a mechanical poke. We had read reports of research indicating that in laboratory animals, and presumably humans, nerve impulses were not conducted along the nerve below a body temperature of 9–10°C, while in hibernators, conduction was not affected down to body temperatures of 2–3°C. In an atomosphere of excitement and anticipation, John Callaghan and I discussed the prospects of an electrical stimulator or pacemaker for the heart.

At the same time, our hypothermia research had turned to the problems of rewarming. We were in need of help from electrical engineering to test the possibility of rapidly rewarming animals, and later patients, with a high frequency diathermy machine. It would be more practical and esthetically more acceptable than plunging them in warm water after surgery. We thought that perhaps the same electrical engineer could help us with the proposed pacemaker.

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I received help from the Radio and Electrical Engineering Division of the National Research Council in Ottawa, where a brilliant electrical engineer, Jack Hopps, had been studying the pasteurization of beer (of all things) by radiofrequency rewarming. Hopps was assigned to our laboratory and given authority to travel back and forth between Ottawa and our basement laboratory in the Banting Institute. On reviewing the available literature, the only reports were the imaginative experiments of J. MacWilliams of London in 1887 and of A.S. Hyman in 1932. Hyman used a hand crank device that could operate for eight minutes, which was not suitable for human use. It was obvious that the field was still open. In order to create a pacemaker where we knew the character of the electrical stimulus, a Grass stimulator was obtained. It delivered electrical current in periodic bursts of any desirable waveform, duration, and frequency. We wanted a delicate electrical stimulus that stimulated the natural pacemaker and that produced no damage to heart muscle.

Following our initial laboratory experience, there were four other occasions in animal surgery where the heart arrested in standstill at a body temperature approximately 19–20°C with the chest open. Stimulating the surface of the heart with the Grass stimulator restored the heart action. In two dogs, electrical control of the heart for 10 and 30 minutes resulted in normal spontaneous heartbeat and recovery, no doubt in part due to unplanned spontaneous rewarming.

Hopps and Callaghan then commenced a careful and painstaking series of experiments: to assess the electrical activity of a normal heart; to determine comparable pulse characteristics that were most effective and safe; and to decide on the best method of delivering a stimulus to the heart. It became apparent that the electrical stimulus supplied to the heart must be of short duration. It was finally decided that a pulse wave with a sharp rise and a 2 ms duration stimulated the normal P wave on the electrocardiogram. The current should be low. With the heart exposed, the sinoauricular node could be stimulated using an electrode at the tip of an insulated rod. It was a single electrode with the other "dispersive" electrode on the chest wall (Fig. 1).

To stimulate the heart without opening the chest, Hopps took a standard Cournand cardiac

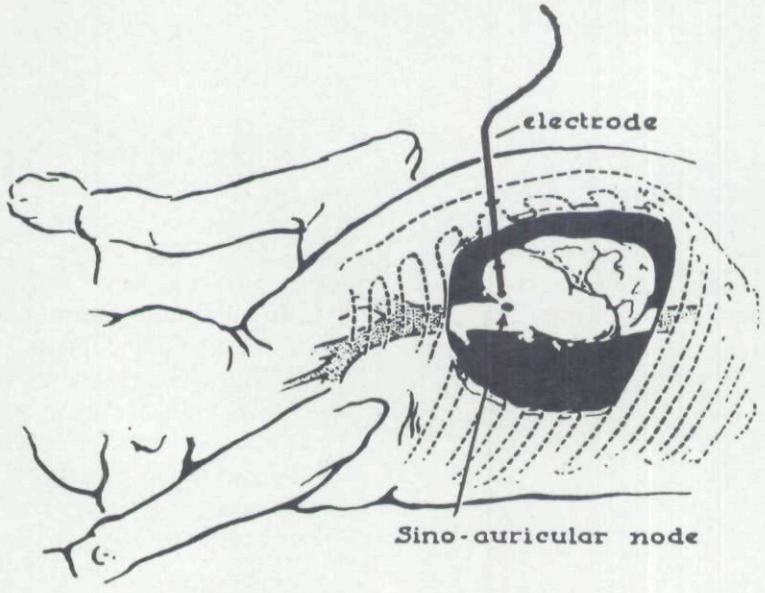

Figure 1. *The "two point" electrode in external contact with the sinoatrial node, after passing through separate incisions in the chest wall and pericardium. In this diagram, the chest is opened and the heart is exposed. Direct stimulation of the surface of the heart is carried out by an external electrode that is held in the operator's hand. The tip of the electrode is placed on or near the area that contains the natural pacemaker (sinoauricular node). Reported in* Annals of Surgery, *1951.*

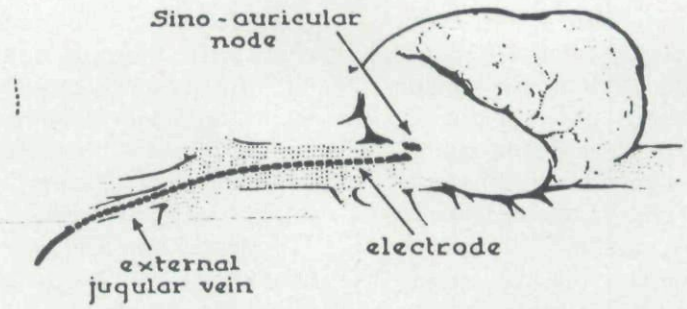

Figure 2. *Intracardiac application of the electrode to the deep surface of the sinoatrial node (insertion through the external jugular vein). Reported in* Annuals of Surgery, *1951.*

catheter and adapted it by passing a wire down the inside of the tube with a ring electrode mounted at the tip. This catheter electrode could be passed down a vein in the neck of a dog to be inside the heart and near the sinoauricular node. The second electrode was attached to the edge of the wound. It proved effective. With his usual perception, he decided that having both electrodes in the one catheter would channel the electrical stimulus to the desired area and avoid the muscle twitching caused by the second electrode. But would it work? He passed both wires down the

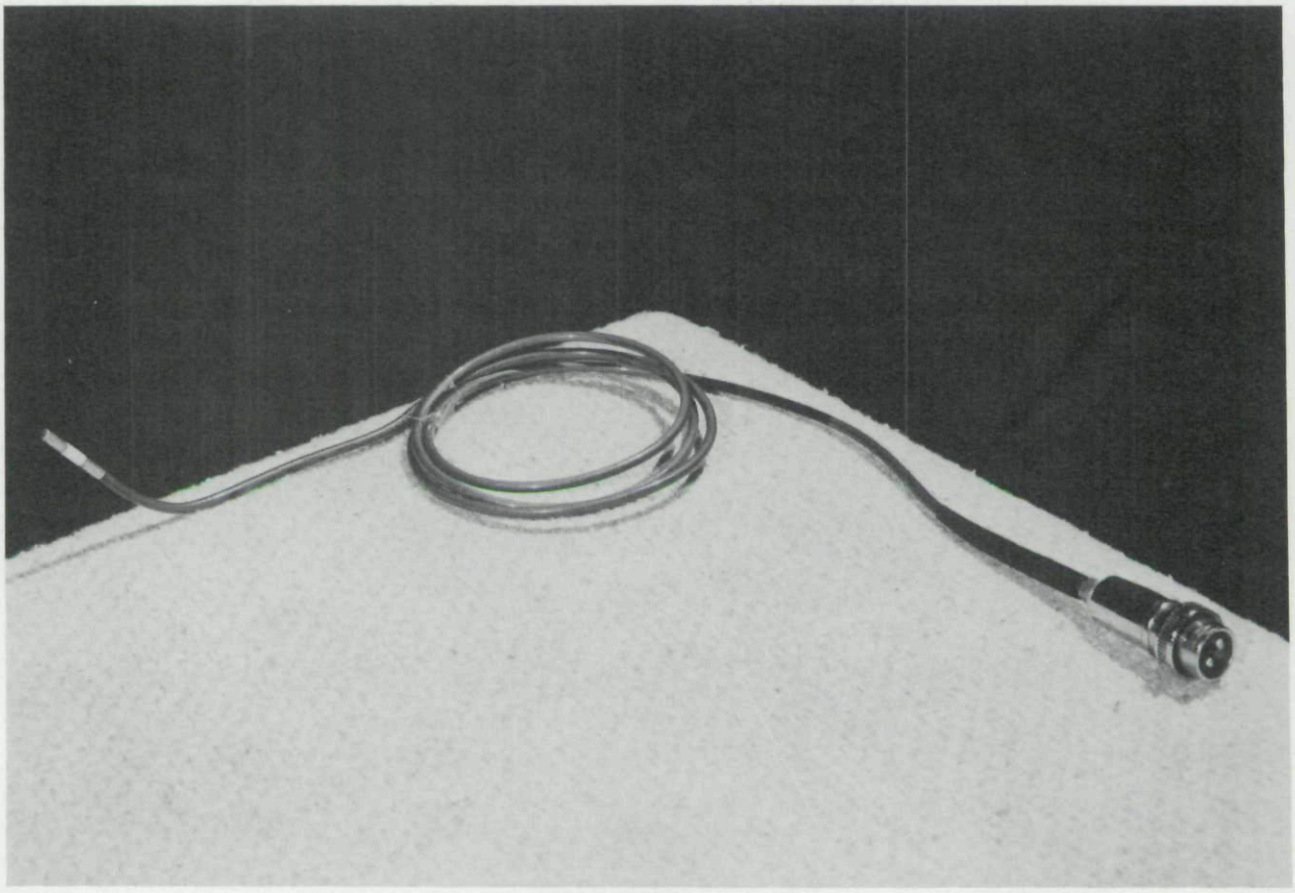

Figure 3. *The intravenous catheter devised by Jack Hopps.*

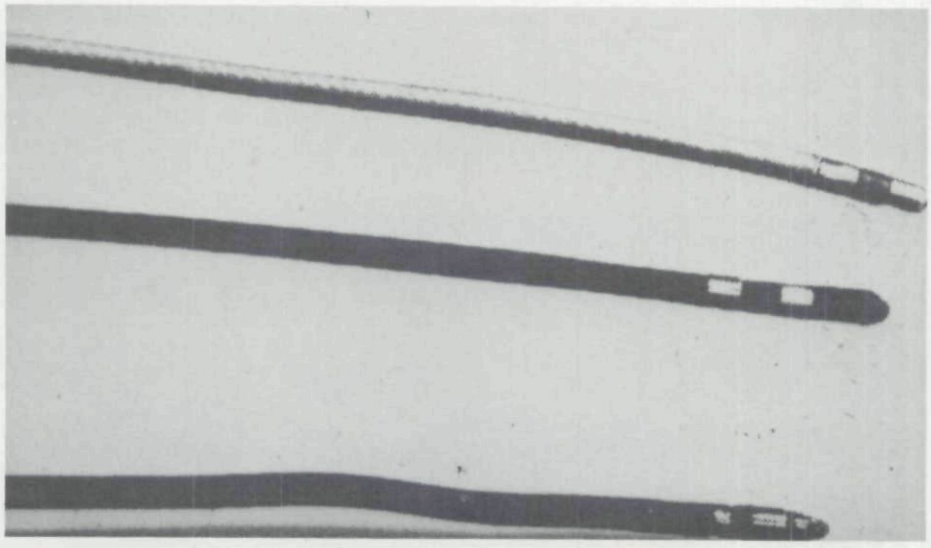

Figure 4. *The intravenous catheter can conduct one (unipolar) or both (bipolar) stimulating wires. National Research Council, 1950.*

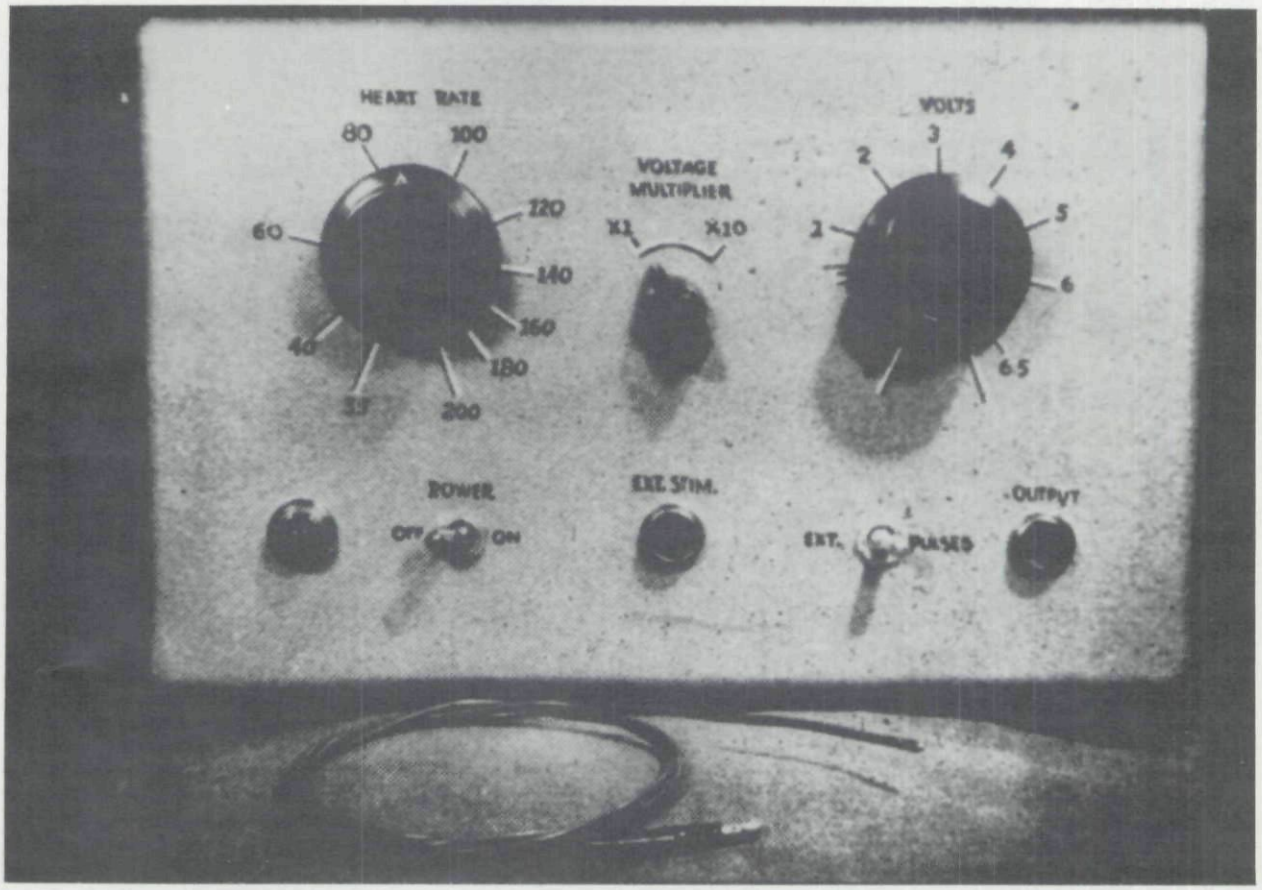

Figure 5. *The original pacemaker stimulator designed by Jack Hopps for use in the Banting Laboratory.*

catheter that attached to two small ring electrodes, insulated from each other at the tip. It did work—and more effectively. This was the so-called "bipolar" catheter electrode to stimulate the lining of the heart (Figs. 2, 3, and 4).

Once the desired pulse features were determined, Hopps retired with the experimental data to his electronics laboratory in the National Research Council in Ottawa. There he designed and built an efficient portable pacemaker unit incor-

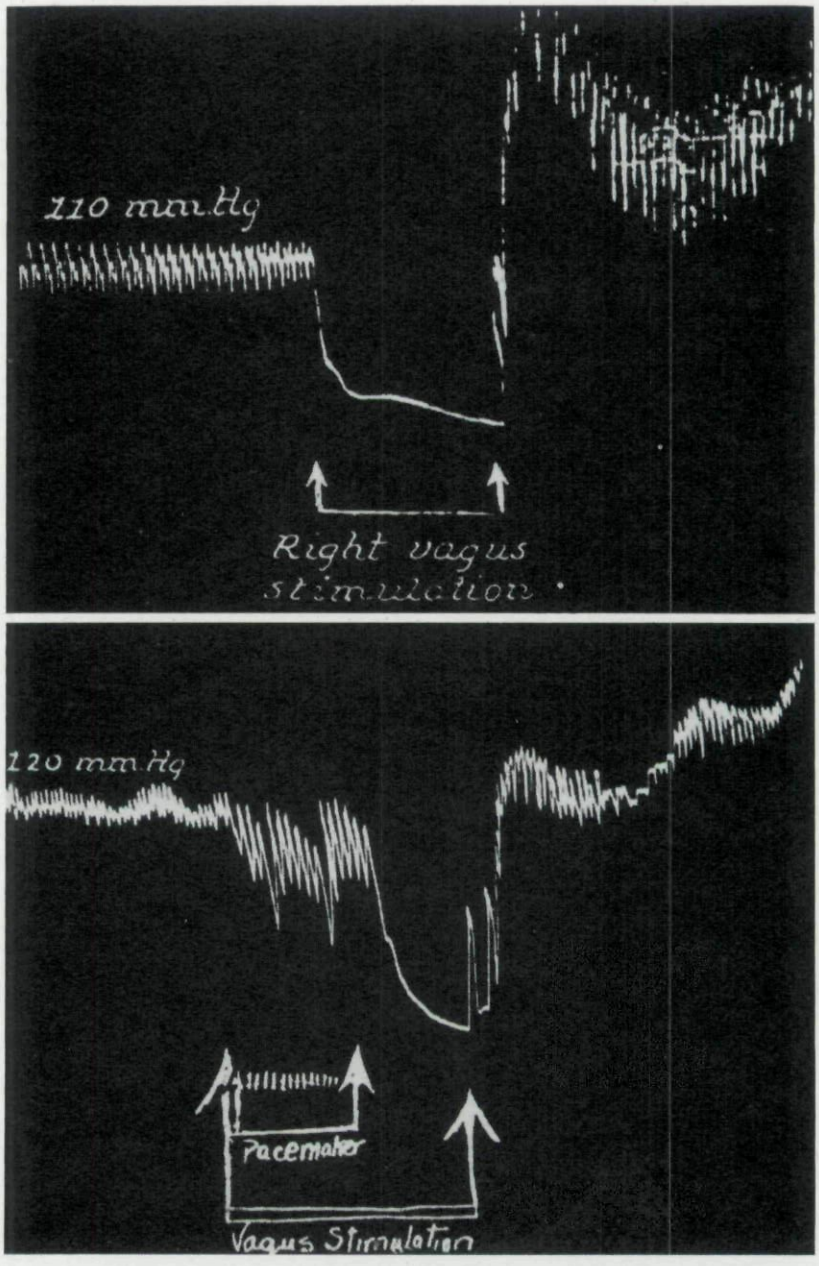

Figure 6. *Heart rate and blood pressure were recorded on a smoked drum before the days of electronic recording. In each experiment, the pacemaker would restore the heartbeats and the blood pressure during a period of induced cardiac arrest.*

porating the desired electrical features with a specialized circuit. It delivered what had been established as the ideal current and electrical pulse wave (monophasic or biphasic). It allowed dial control of heart rate and voltage. The unit was about 12 inches by 7 inches—the size of a mantel radio of that era (Fig. 5).

The first experiments were performed on dogs in the Banting Institute, with the pacemaker electrode inserted by cutdown through the jugular vein. When the stimulating tip was in the region of the sinoauricular node, there was evidence on the electrocardiogram to confirm its position as an atrial pacer. The blood pressure and heart rate were recorded by a fine pointer that produced a tracing on a rotating drum of smoked paper (Kymograph). At 20°C the heart stopped, the pacemaker was turned on at a rate optimum for that body temperature, and it immediately took control of cardiac action. The blood pressure improved and cooling progressed without event: 19°C . . . 18°C . . . with a good stable appearing electrocardiogram. However, at a body temperature of 17°C, the heart suddenly stopped and we were thus un-

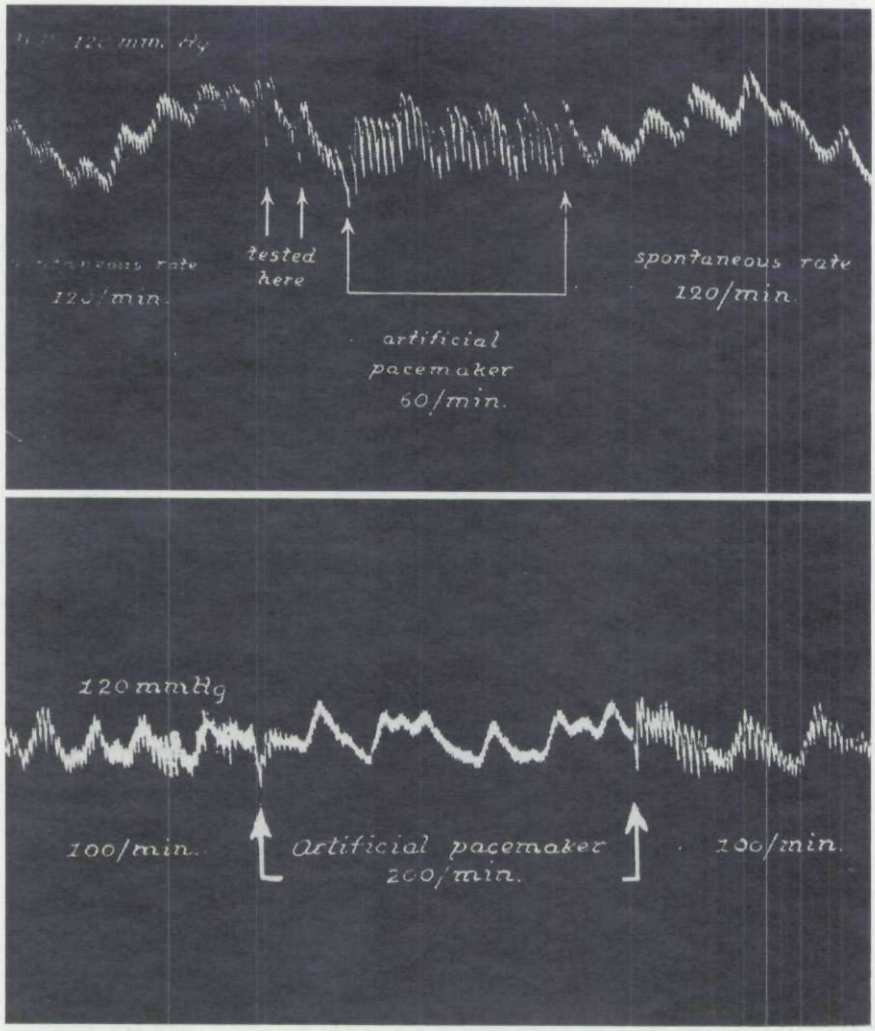

Figure 7. *The pacemaker dominated the natural pacing mechanism of the heart. The figure shows the heart rate of 120 beats per minute, reduced to 60 beats per minute and a rate of 100 per minute being increased to 200 per minute.*

able to reduce the lower limits of cooling by more than 2°C since the pacemaker would no longer capture. It was obvious, however, that the pacemaker could be used to improve safety at moderate levels of hypothermia and to facilitate recovery during rewarming. The next obvious step was to study the use of the pacemaker at normal body temperatures wherein cardiac arrest was obtained by vagal stimulation. In each instance, the pacemaker would restore cardiac action and blood pressure during the arrest period (Fig. 6).

During the course of these experiments, the pacemaker was applied to the normal beating heart, and the vagus nerve stimulated. We were amazed to discover that the heart was effectively controlled by the external pacemaker. It then dominated the natural pacing mechanism in a consistent manner even though the normal heart rate of the dog was 120 bpm. The pacemaker could regulate the heart action and increase the rate to 200 or lower to 60 bpm. The blood pressure, interestingly enough, remained unchanged regardless of the heart rate due to build-in reflexes (Fig. 7).

Experiments during hypothermia and at normal body temperature were duplicated using a bipolar stimulating electrode applied to the sinoauricular node; to the external surface of the exposed left ventricle; and, without opening the chest, by way of the intravenous electrode, the sinoauricular node. All of these experiments were repeated many times in controlled studies with careful collection and analysis of the data, all recorded on a smoke drum and by motion picture.

The results of these experiments were presented at the American College of Surgeons Meeting in Boston, Massachusetts on Octobert 23, 1950. John Callaghan's presentation was carried out with his usual style. Our slides and movie dramatically demonstrated the remarkable ability of the pace-

Start Stopped Hearts By Toronto Machine

By WILLIAM L. LAURENCE

New York Times Special to The Globe and Mail. Copyright

BOSTON, Oct. 23. — An artificial electrical pacemaker that has been used successfully in animal experiments to make hearts that have stopped beat again was described here today before the opening sessions of the annual clinical congress of the American

New Heart Machine May Cut Battle Exposure Fatalities

Figure 8. *Photograph of the* New York Times *article by William L. Lawrence.*

maker to control the heart. The daily Congress newspaper noted that it was one of the scientific highlights of the day. We were sought out by newspaper reporters who were naturally entertaining rather grandiose ideas as to the future of such a contraption. William L. Lawrence, the reigning dean of science writers, honored us by selecting our paper as the subject of an article in the *New York Times* (Fig. 8).

Then it was back to the laboratory in Toronto and reality, where further developmental work was required. At the time of the report to the American College of Surgeons, Dr. Callaghan had already responded to five emergency calls to the operating room for patients with mediastinal invasion of bronchogenic carcinoma with cardiac arrest or severe bradycardia during thoracotomy. Intracardiac catheter electrodes were rapidly passed through a vein in the arm or groin and connected to the pacemaker in an attempt to restore the function of the failing heart—without success. The cases were not suitable for pacing, but Callaghan decided years later that had he pushed the catheter just two inches further, beyond the sinoauricular node and into the right ventricle, he might have achieved a satisfactory and dramatic response.

We had no sooner returned from Boston than we received the first inquiry. A letter written one week after our presentation arrived from Paul Zoll,

Figure 9. *The combined stimulator-defibrillator designed by Jack Hopps and produced by the National Research Council in Ottawa. A foot pedal to trip the single 200 volt defibrillating shock and special electrodes that are held on either side of the heart to conduct the electric current through the organ are noted. National Research Council, 1950.*

who expressed an interest in our pacemaker and said he was "most eager to get more information about the details of the stimulating apparatus." After an exchange of letters, Hopps and Callaghan finally supplied Zoll with full details of the NRC circuit diagram. Soon after this, he published an article reporting the interesting and successful use of a pacemaker (stimulator) in two patients with heart block. This was the first successful treatment of heart block in humans with a pacemaker. His work drew the attention of the medical profession to the potential value of the pacemaker in treating this form of heart disease. Unfortunately, Zoll forgot to indicate in his article the source of the electric circuit diagram that he used in his pacemaker.

With the dawn of open heart surgery in the early 1950s, opportunities for electrical stimulation of the heart expanded. In 1951, Hopps and his coworkers at the National Research Council produced a combined stimulator-defibrillator (Fig. 9). Dr. Walton Lillehei, in 1956, designed a small portable external pacing unit operated by battery power, which could be used for a period of ten days to two weeks. The pacemaker was used occasionally in a few centers for the treatment of human patients. It literally sat on the shelf for nine years awaiting improved technology. The real breakthrough that allowed construction of a permanently implantable pacemaker was the development of transistor circuitry. Ake Senning of Stockholm was the first to accomplish this in 1958. His patient lives today. It was the beginning of an explosion of knowledge that has produced the incredible era of cardiac pacing that we now know.

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