

Ambulatory electrocardiography: The contribution of Norman Jefferis Holter

“Through training and observation, I have learned that honesty and integrity are not just clichés but sources of both self respect and enlightened self interest.”¹

—N.J. Holter (1914–1983)

ABSTRACT: Norman Jefferis Holter was an American physicist who made a significant contribution to medical technology with his invention of the first portable cardiac monitoring device. Patients today benefit from both ambulatory electrocardiography and the other devices made possible by it, such as pacemakers and implantable cardiac defibrillators. Now 60 years since Holter found a way to make a wearable monitor, “Holter” has become a synonym for the simple yet effective device that is used routinely by physicians worldwide to detect, document, and characterize cardiac rhythm abnormalities.

Norman Jefferis “Jeff” Holter was a pioneer in the field of ambulatory electrocardiography, and the inventor of the portable cardiac telemetry device that bears his name and is used worldwide to this day. He famously made a case for continuous ambulatory cardiac monitoring by comparing the collection of heart data with the work of a mining engineer, who “does not assay a mountain of ore by testing one rock.”¹

Jeff Holter’s words resonate with many physicians who have stood by the bedside of a patient with a suspected rhythm disturbance, only to have a benign-looking electrocardiogram on hand. As a single rock sample cannot reveal the riches of ore within a mountain because of sampling error, a single ECG may not capture a transient symptomatic arrhythmia. Holter’s invention revolutionized the field of diagnostic cardiology by providing a noninvasive way to record the heart’s electrical activity. His technological contributions have since paved the way for devices such as pacemakers and implantable cardiac defibrillators, which allow for management of unstable arrhythmias.

Jeff Holter

Jeff Holter was born on 1 February 1914 in Helena, Montana. He was a science enthusiast throughout high school, pursuing the study of chemistry at the University of Southern California in 1938 and the study of physics at the University of California, Los Angeles, in 1940. He earned a master’s degree in each field and had the opportunity to study nerve conduction testing with Dr Joseph Gengerelli of UCLA.^{1,2} Although he never pursued a medical degree, his foresight would eventually influence the practice of medicine by helping clinicians evaluate and treat cardiac arrhythmias.

During the Second World War, Holter worked as a senior physicist for the US Navy’s Bureau of Ships and conducted research on ocean wave characteristics. His contributions were many, including the development of amphibious operations. He also led a team of oceanographic engineers to Bikini Atoll to perform

Dr Ioannou is a cardiology fellow at the University of British Columbia. Ms Ignaszewski is a medical student at the Medical University of Warsaw in Poland. Dr Macdonald is a staff cardiologist at St. Paul’s Hospital in Vancouver.

This article has been peer reviewed.

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postwar atomic testing. His Operations Crossroads project looked into the effects of atomic explosions on underwater wave currents.^{1,3}

After the war, Holter returned to his hometown of Helena and founded the Holter Research Foundation, a personally funded scientific endeavor located at the back of the family hardware store. His work included further study and development of electrophysiological telemetry with Dr Gengerelli.

Years before the invention of the modern transistor, Holter succeeded in recording electroencephalographic information from a boy on a bicycle, Albert, with electronics considered large and crude by today's standards. Due to the technological limitations of the time, the signal-to-noise ratio of encephalograms proved disappointing. The voltage of the heart was known to be significantly greater than that of the brain, providing a much more robust signal. In a move that was as ingenious as it was practical, Holter switched the electrodes from the head to the chest, and cardiac telemetry was born.^{1,3,4}

Holter's first radio-electrocardiograph recording was made on a 38-kg device⁵ that was strapped on like a backpack (Figure). From a practical standpoint, the developing technology had a long way to go before it could be implemented clinically. Short transmission capabilities also limited

radio broadcasting of telemetry data. A smaller tape recording device that was developed subsequently could be housed within a briefcase. For the very first time, a truly portable cardiac telemetry device was available. Holter ultimately refined the device, reducing it to a size of 19.5 × 9.8 × 4.6 cm and a weight of 1 kg. Realizing the potential benefit of such a monitoring device, Holter and his colleagues sold the patent to Del Mar Avionics, a well-known airline equipment firm that became the leading manufacturer of the device for over 40 years.⁶ With increased capital support from Del Mar, Holter was able to refine his invention into a practical clinical tool. The first reported use of ambulatory electrocardiography was in 1954, as published in the *Canadian Medical Association Journal*. Since that time, thousands of studies and case series have been published involving ambulatory electrocardiography.^{1,3}

Current monitoring devices

The portability of the Holter monitor has since progressed to such an extent that the device now in use resembles a small music player rather than the original bulky backpack-type device of 1947. Today's Holter is usually worn around the neck or around the waist attached by a belt, where it allows for patient monitoring during daily activities. This noninvasive



Figure. Jeff Holter with his original 38-kg radio-electrocardiograph recording device in 1947.

monitoring can be achieved during a spectrum of activities, from restful sleep to extremes of exercise. Ambulatory electrocardiography continues to be used today primarily to investigate presumed or known cardiac arrhythmias, and is often ordered for patients with symptoms of palpitations or syncope. It is also used to evaluate response to pharmacotherapy for a given rhythm or heart-rate-related condition. Several formats and variations of ambulatory electrocardiography exist, including 24- and 48-hour monitoring, use of event recorders, and, more recently, use of implantable loop recorders that can last several years.

The type of ambulatory electrocardiography cardiac monitoring device chosen depends on the indication for evaluation as well as on the frequency of symptoms. If symptoms

Table 1. The diagnostic value of ambulatory ECG monitoring revealed by the correlation between symptoms and the timing of the arrhythmia.

		Arrhythmia documented during monitoring	
		Yes	No
Symptoms present during monitoring	Yes	Symptoms attributable to arrhythmia	Arrhythmia as cause of symptoms likely excluded
	No	Asymptomatic arrhythmia	Test non-diagnostic

Courtesy of the Medical Services Commission of BC, Guidelines and Protocols Advisory Committee. Ambulatory ECG monitoring (Holter monitor and other devices). Effective 15 April 2013. www.bcguidelines.ca

are daily, a standard 24- or 48-hour Holter monitor is usually sufficient. If symptoms are less frequent, such as weekly, an event recorder can be considered, since this allows a patient experiencing symptoms to initiate an electrocardiographic recording with the push of a button. Such a recording will document the cardiac rhythm shortly before initiation (due to the continuous loop recording algorithm) as well as during the symptomatic episode. Follow-up interrogation of the device, either by telephone or in a clinical setting, can then compare symptoms with the recorded cardiac rhythm to establish a diagnosis (Table 1).

Newer technological advances have led to the development of subcutaneous implantable loop recorders that can be used when symptoms deemed to be low risk occur only a few times a year. Implantable loop recorders operate continuously for up to 3 years, and can be interrogated transcutaneously at any time using a portable computer interrogator, much like that used for pacemakers.

The presence of ischemia may also be detected using ambulatory electrocardiography by evaluating for ST-segment changes and abnormalities. However, ST-segment analysis based on ambulatory electrocardiography is neither sensitive nor specific for evaluation of ischemic heart

disease. If ST-segment abnormalities coexist with ischemic symptoms, further risk stratification and evaluation should be undertaken.

BC guidelines

BC guidelines for ambulatory monitoring were published in 2004 and revised in 2007 and 2013. The guidelines in use rely on further review of the existing evidence as well as suggestions and consensus from practising cardiologists.⁷

Originally, four recommendations were listed in 2004. These included patient selection, choice of device, monitoring in complex cardiac conditions, and patients deemed appropriate for ambulatory ECG monitoring. These recommendations have largely remained unchanged. The 2013 guidelines have simplified appropriateness criteria based on the four different available ambulatory devices (Table 2).⁸⁻¹³

The choice of device depends on several factors, including the frequency of patient symptoms, ability to activate the device and record symptoms in diary form, as well as accessibility of such devices. Consultation with a cardiovascular specialist may help determine the most suitable investigation according to the clinical scenario as well as in special populations listed in the updated guidelines.⁷

Ambulatory electrocardiography

can diagnose new paroxysmal atrial fibrillation in patients with stroke in 1.0% to 5.4% of cases.⁷ The role of treatment of ventricular ectopy for mortality reduction after a myocardial infarction is also still unclear, and therefore use of ambulatory electrocardiography cannot be routinely recommended.⁷

Patients helped worldwide

Jeff Holter once said, “When my heart starts skipping, they’ll have the longest normal base line in history.” On 21 July 1983 he passed away at the early age of 69 in his hometown of Helena. His significant contributions to medical science, including advancements in nuclear medicine,³ are equaled only by his generous gift to medicine, the Holter monitor. Over 60 years since its invention, this simple yet effective device continues to be used routinely by physicians to detect, document, and characterize rhythm abnormalities, and has entered the medical lexicon, making “Holter” synonymous with the device itself. As well, Holter’s pioneering technology has paved the way for the development of other cardiac devices, including pacemakers and implantable cardiac defibrillators, all of which have helped hundreds of thousands of patients worldwide.

Competing interests

None declared.

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Table 2. Appropriateness criteria based on the four different available ambulatory devices.

Device	Frequency of symptoms ⁹⁻¹⁰	Device characteristics ^{9-10,13}	Duration of test ⁹	Yield*
Holter monitoring	Daily (mainly palpitations)	External device worn constantly, with continuous tape recording which is retrieved and interpreted once the device is returned. Only suitable for patients with symptoms occurring within the monitoring period, or when establishing risk/response to therapy.	24 hours [†]	Syncope <20% ¹¹ Arrhythmia ~35% ⁹
Event recorders[‡]	Weekly to monthly	External device worn intermittently, stores data when activated by patient during an event. Not suitable when investigating syncope since a patient cannot activate it if suddenly unconscious.	Up to a month	Arrhythmia ~60% ¹⁰
External loop recorders[‡]	Weekly to monthly	External device worn constantly, with memory loop recording capability. The data is stored before and after the patient activates the device. There is also a built-in automatic trigger algorithm that allows the device to store data for asymptomatic arrhythmias. Suitable as a first line investigation for patients suspected with an arrhythmic cause for syncope.	Up to a month	Syncope ¹¹ ~25–40%
Implantable loop recorders[‡]	Less than monthly	Device is subcutaneously implanted, with a loop memory recording that stores data once it is manually activated by the patient or activated automatically. Suitable for patients with spontaneous symptoms with recurrent unexplained syncope.	Up to 3 years	Syncope ¹² ~70% Arrhythmia ⁹ ~70%

* Diagnostic yields are only approximate since they are dependent on many variables.

[†] In some circumstances, the duration of a Holter monitoring can be extended. However, the diagnostic yield of an extended time or repeat test is low.

[‡] These tests are usually arranged in consultation with a specialist.

Courtesy of the Medical Services Commission of BC, Guidelines and Protocols Advisory Committee. Ambulatory ECG monitoring (Holter monitor and other devices). Effective 15 April 2013. www.bcguidelines.ca

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