Non-Invasive Physiological Measurements

Volume 1

edited by Peter Rolfe

NON-INVASIVE PHYSIOLOGICAL MEASUREMENTS

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Peter Rolfe

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PREFACE

The desire to detect, observe and quantitate physiological phenomena has been the stimulus for the development of a vast and ever growing number of techniques, and for the evolution of physiological measurement as a specialist subject. Within this general area of development there has, in recent years, been a trend towards the perfection of measurement procedures which are not disturbing, intrusive or cumbersome to the subject. Now the combination of the inventiveness of the workers in this field and the exploitation of advances made in physics, electronics and computing has made the non-invasive measurement of a large number of physiological variables both feasible and useful in research and clinical care.

One aim of the book is to demonstrate the breadth of the subject of non-invasive measurement, in order to encourage both the routine use of such techniques and their further development. This volume includes work on well-established topics, such as blood pressure measurement and phonocardiography, on the very new techniques of transcutaneous blood gas measurement and evaporative water loss measurement, as well as on three different applications of the still controversial topic of electrical impedance measurement. The ultimate, and perhaps attainable, goal of many workers in this field is to see all physiological measurements being made by non-invasive techniques. This presents a huge challenge to us all, but I hope that a consideration of the advances represented by the topics in this book will provide us with the necessary encouragement to take on the challenge, and succeed.

The interest in non-invasive techniques is not confined to the clinical sphere, where there is an obvious need, it also exists amongst physiologists engaged in fundamental animal research. These workers are increasingly turning to measurement techniques which have adequate accuracy and at the same time do not disturb the physiological process being examined. At present not all of the available techniques are ideal for these purposes, but improvements continue to be made. It is hoped that, in addition to the research physiologist, those involved in physiological measurements in anaesthesia, intensive care, obstetrics and paediatrics will find this book of interest and of value, and that it will attract medical and physical scientists, technical and nursing staff alike.

Finally, I would like to thank all the contributors. I am indebted to them for responding so enthusiastically to my request for their involvement, particularly as I know of the sacrifices which must often be made to write about one's work.

January 1979 PETER ROLFE

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1. AN INTRODUCTION TO NON-INVASIVE CARDIO-DIAGNOSTIC TECHNIQUES

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Diagnosis in medicine has for centuries depended on artistry and skill. Until the latter part of the last century, the only available instruments for assessing the internal functions of the body were tubes designed for looking into every available orifice and the stethoscope. The only alternative was the cold white light of surgery with all its attendant risks and pain. The final confirmation of diagnosis was made in the post-mortem room. Developments of surgery in the twentieth century created an urgent need for improved diagnostic techniques.

Nowhere has surgical technique leapt ahead of diagnostic skills more rapidly than in the field of cardiac surgery. Sir Henry Souttar's first operations on the mitral valve in the heart at the London Hospital in 1923 failed not because of poorly conceived operative procedures, but because he operated on patients with a diagnosis of mitral stenosis—narrowing of the valve; the valve disease was in fact mixed with some narrowing of the valve and, more importantly, mitral regurgitation with blood leaking through the improperly closing valve, which was accentuated by his operation. Even today, with improved post-operative care, the wrong cardiac surgical operation, which makes the circulation less efficient or an inadequate correction of a defect combined with the effects of the operation, may end with a dead patient. In Souttar's day, when management of the opened chest was less adequate, it was not surprising that his patients succumbed.

Hypothermia, utilizing surface cooling of the body to slow down metabolic processes, was the first technique to be used widely in cardiac surgery. This enabled surgeons to arrest the circulation for just long enough to repair a simple defect. With only four to eight minutes of safe operating time inside the heart, clinicians had to differentiate between operable lesions like the sucundum atrial septal defects and the clinically similar, but then virtually inoperable, ostium primum septal defects. At best an error meant an unnecessary operation. The differential diagnosis was achieved by painstaking astute clinical observation using the time-honoured routine: a detailed case history; inspection of the patient; palpation and percussion of the chest; and auscultation, aided by the oldest non-invasive instrument, the stethoscope. Clinical diagnosis had reached its zenith. The electrocardiogram, a non-invasive instrument developed before the turn of the century, could, when the case was typical, give useful confirmatory evidence.

By the late 1950s the heart–lung machine made it possible to open the last unexplored cavities in the human body—the ventricles of the heart—for long enough to perform more beneficial surgical procedures. Open cardiac surgery became a safe practical routine by the mid 1960s.

At that time there was a great tradition of clinical cardiology. In skilled hands this diagnostic art was remarkably accurate. The whole art depended on time-consuming, meticulous clinical observation of sign and symptom. Greater credit should be given to these painstaking clinicians than is generally accorded to them. They described in detail most of the clinical entities which we now recognize, and explore with our new generation of non-invasive instruments. Nevertheless, the reliability of diagnosis was inadequate to support tens of thousands of heart surgery cases. The response to the need for accurate anatomical diagnosis in quantity was met by physicians and physiologists with the development of the cardiac catheter X-ray laboratory.

The cardiac catheter is a narrow bore, radio-opaque tube which can be threaded under X-ray screening control into various chambers of the heart. Several alternative techniques can be used to explore the heart. The lumen of the catheter can be connected to a pressure transducer to determine the pressures in the heart and great vessels. Samples can be withdrawn to assess the oxygen content of blood at various sites. Radio-opaque material can be injected to visualize the anatomy of the chamber into which the injection is made and to visualize the chambers into which the flow of blood carries the bolus of dye-containing blood. The catheter may be threaded into the right side of the heart, from a convenient arm, leg or neck vein. At first, catheterizations were confined to the right side of the heart unless the patients had defects in the septum through which the catheter could pass. Some information about the left side of the heart could be derived by advancing the catheter up the pulmonary artery and wedging it in a small pulmonary artery branch. The end hole in the catheter would then be in communication through the pulmonary capillary bed with the left atrium, producing a damped left atrial pressure. Techniques soon evolved which enabled the catheter to be threaded into the left side of the heart. This has been done by several routes. Each of the methods involves risk to the patient which is additional to the hazard of exposure to X-ray and infection. Some routes which have been used are from the left main bronchus through a bronchoscope, directly through the chest wall and retrogradely via an artery through the aortic and mitral valves.

The amount of information about the anatomy of the heart which can be obtained with the aid of the injection of radio-opaque substances, rapid X-ray film changers and cine X-rays produce remarkably accurate anatomical diagnosis.

The mortality rates in catheter diagnosis laboratories have continued to fall. In good centres death occurs in one case per several thousand. Nevertheless, there has been one recently reported series with a 12% mortality rate from some cardiac catheterization from centres in the USA. Even in the best centres there is a significant morbidity associated with cardiac catheterization. Some pain is also inevitable. Each right-sided procedure places in jeopardy a vein which may be a lifeline for a patient undergoing major surgery in future. The future of patient exposure to diagnostic X-rays is unclear. A single session in a catheter laboratory will expose a patient to a dose of X-rays which is orders of magnitude in excess of the dose acceptable for a worker in the nuclear power industry over a lifetime. Catheterization of the heart is reserved for patients who are being assessed for cardiac surgery.

Nevertheless, any case for a new cardio-diagnostic system must not be based on negative reasons. A new case is emerging for the development of non-invasive instrumentation, arising from the excellence of the catheter laboratories themselves.

A surgeon can be reasonably sure that at operation he will see the anatomical configuration which the cardiologist has described. What he cannot be sure of is that the patient will survive the correction of the defects. Additional information to inform the surgeon about the state of the contractile element of the heart, the muscle in the left ventricle on which the patient's life depends, is required.

A new diagnostic concept has to be understood before the potential of non-invasive instruments can be appreciated. They produce a different type of information from that which is obtained in the catheter laboratory. Non-invasive instruments give information about movements of blood, the performance of the contractile element of the heart muscle, and they measure mechanical phenomena. They do not produce images. In engineering terms, they do not provide a view of the inside of an engine, the state of the piston rings, the valves, etc., they give performance data, power outputs and fuel consumption figures. Contemporary diagnostic instruments produce good images and poor performance figures.

Mechanical performance data represent the information which is probably best produced by non-invasive instruments. Mechanical data can only be obtained from the catheter results by painstaking measurement and computer analysis of angiocardiographs and pressure traces.

The natural history of cardiac disease is not fully understood. The reasons for the ten-fold increase in death from coronaries in the UK since the 1930s are not known. Population screening to define the natural history of cardiac disease, to identify the patients who are developing the disease and, most importantly, to monitor the effectiveness of any preventive measures which might be postulated, must be seriously considered in the near future to meet public demand. Clearly any population monitoring will have to be based on non-invasive instrumentation.

Unfortunately, non-invasive instruments in their present state of development are not capable of meeting the diagnostic tasks required of them. Rarely can a single non-invasive instrument at the present time add enough information to clinical diagnosis to eliminate the need for cardiac catheterization; sophisticated echo-cardiographic equipment is perhaps showing the greatest potential for non-invasive final diagnosis. Certainly no single existing instrument can be used to screen for the presence of early manifestations of cardiac disease and none in their present state can be used alone to follow the progress of established disease.

The medical profession is being forced to consider more widespread use of non-invasive techniques by a number of factors: public demand; pressure from instrument manufacturers extolling the virtues of their instruments; insistence from bio-engineers that their inventions and developments actually work; the high and increasing cost of catheter laboratories; the difficulty of recruiting staff who are prepared to work in areas where radiation is used; the lobby which is arising out of the awareness that even the small doses of irradiation given for chest X-rays may be damaging to the heart; and doubtless for many other reasons less tangible which influence the progress of medicine, such as the climate of political opinion. The protagonists of non-invasive instrumentation for non-invasive cardio-diagnosis have a challenge to face. Are their efforts measuring up to the potential demand?

Many non-invasive instruments available today have not been fully validated and are, therefore, probably not fully developed. The validation and subsequent development of the instruments are being delayed by a combination of vested interests and lack of training of young cardiologists in their use, due to the inevitable inertia in medicine. Furthermore, the present research effort is only a fraction of that which is desirable in relation to clinical need. The biggest single cause of death in the working population, the disease with the most rapidly increasing mortality and morbidity in the western world deserves a bio-engineering effort to develop non-invasive instruments in proportion to the need.

Before the development of the catheter laboratory, diagnosis had always depended on the integration of small amounts of information from many different sources. The fact that the catheter laboratory produces so much comprehensive and accurate diagnostic information in one session has created a climate of opinion in which physicians tend to seek comprehensive and accurate information from a single instrument. With the possible exception of very sophisticated echo-cardiographic equipment, no such non-invasive instrument exists. No single non-invasive instrument gives hard, factual information about cardiac performance, and no single instrument gives information about the whole cardiac cycle. Perhaps too much is being asked of relatively weak instruments which give only circumstantial evidence about the mechanical performance of part of the contraction or relaxation cycle or the heart muscle. In other walks of life it is commonplace to build up a complete picture from a mass of circumstantial evidence. The western world is used to commenting on and analysing the behaviour of half of the world's population with considerable accuracy, with no direct access to data from the Government. "China Watchers" piece together shreds of evidence to build a complete picture. Police officers throughout the world do not expect the criminal to leave a statement of his identity and whereabouts at the scene of the crime. They expect to build up a case from a mass of circumstantial pieces of information, each one on its own providing only an indication as to who the criminal might be. A haematologist will examine a blood stain, a biochemist will do enzyme studies on a body secretion, the trichologist will study a hair, a finger-print expert the imprint of the suspect's hands, a detective will study a foot print or a tyre mark, a fabric expert a shred of material, and so on, until evidence is complete. It should be possible to combine the comparatively soft data from the large number of different non-invasive cardio-diagnostic instruments available now, and obtain some "hard" facts. In order to do this, there are three stages of evaluation to be undertaken. Each instrument has to be validated against known fact. Does its output really relate in a constant and predictable way to the performance of the heart ? Or is its output a meaningless jumble of signals ? If strict criteria are to be applied to the evaluation of new instruments consideration must be given to established practice. If the ECG had not been discovered at the end of the last century and it were a new discovery of 1979, it would be unlikely that it would be accepted by present-day clinicians. Modern recorders capable of reproducing high-frequency signals would produce a very different signal to the simple