ANALYTICAL AND CLINICAL STUDIES ON ELECTRICAL FIELD PLETHYSMOGRAPHY AS A NEW NON-INVASIVE TOOL FOR MONITORING MECHANICAL ACTIVITIES OF THE HEART

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DEDICATED

TO

MY PARENTS

CERTIFICATE

This is to certify that the thesis entitled "ANALYTICAL AND CLINICAL STUDIES ON ELECTRICAL FIELD PLETHYSMOGRAPHY AS A NEW NON-INVASIVE TOOL FOR MONITORING MECHANICAL ACTIVITIES OF THE HEART" by Bhaskar Bhattacharya is a record of original bonafide research carried out under my supervision and has not been submitted elsewhere for a degree.

August 5, 1982

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ABSTRACT

The existing literature shows that numerous attempts have been made in the past to develop non-invasive techniques for cardiac monitoring. Since the heart is by and large a pump, cardiac monitoring systems should mainly concentrate on observing how efficiently the pump is working. In other words, it is the movement of blood that should be monitored. Among the many non-invasive techniques that exist today, very few are actually related to the movement of blood. Most of them measure the movement of the mucular wall of heart and some measure the electrical activity of the heart responsible for its contraction. Out of the three methods - Impedance Plethysmography (IPG), Displacement Cardiography (DCG), and Electrical Field Plethysmography (FPG) - that attempt to monitor the movement of blood, the latest one, FPG, has been studied in some detail in this thesis.

Initially FPG was proposed as a technique which is sensitive to cardiac movements but relatively insensitive to respiratory changes in the thorax. It is already known that it is not so with IPG and DCG. The effects of various physiological events on FPG output were studied by the earlier workers with an oversimplified model using finite

difference method. However, no attempt was made to investigate the effect of hematocrit percentage (which have been proved to be an important parameter in IPG) and the optimum placement of pick-up electrodes. The effects of physiological activities such as contraction of heart and changes in the lungs have been studied in this thesis with a more realistic two-dimensional model using finite element method. The effect of hematocrit percentage and the optimum location for placement of the pick-up electrodes have also been investigated. The study confirmed the earlier finding that FPG is highly sensitive to changes in cardiac dimension compared to changes in the lungs. Also, the effect of hematocrit percentage was small and the optimum position of pick-up electrodes suggested by the study corresponded very well with the experimentally obtained optimum locations.

The simulations with the two-dimensional model suggested that the technique may be used for measurement of stroke volume as envisaged by the earlier researchers. It was even anticipated that the amplitude of the FPG waveform has definite correlation with the stroke volume. Reflecting upon this possibility, it occured that if such a correlation exists, the relationship between FPG output and change in cardiac volume should be monotonic. This possibility could not be investigated with the model developed earlier because the heart had to be moved and contracted in several stages to make such a study possible. Hence, a simple model, where an analytical solution for the pick-up potential is possible, was considered. The study indicated that depending on the position and mean volume of the heart, and the position of the pick-up electrodes, the relationship may become non-monotonic. Therefore, given the complexities inherent in thorax, it was concluded that a monotonic relationship between the two variables cannot be guaranteed. The above study indicated that a plethysmographic application of FPG will not be simple and surely the amplitude of FPG will not completely serve the purpose.

Looking back at a similar technique, IPG, it was seen that most of the signal in IPG is derived from aortic distension. Study of the effect of aortic distension on FPG necessitated the development of a three-dimensional model which was kept simple for the sake of easy maneuverability. Simulation of various physiological events in the simple three-dimensional model showed that FPG output is mostly affected by cardiac contraction only. It was found that aortic distension, which plays an important role in IPG, had very little effect on FPG output. The heart was contracted in two steps to have a feel of the dynamic behavior of the system. It was found that in the first step the FPG output decreased with the electrodes placed at the optimal locations and in the second and final step FPG output increased with further contraction of heart. This clearly demonstrates the presence of non-monotonic behavior even in such a simple system. Equidifference lines were plotted on the anterior surface of the model corresponding to each of the physiological activities to see the changes in potential distribution on the surface brought about by them. It was noted that the pattern for contraction of heart was entirely different from the pattern for changes in the lungs. This suggests that both cardiac and lung activity can be monitored in isolation with FPG technique.

The fact that respiratory interference can be almost completely eliminated from the FPG of normal subjects by proper placement of electrodes was observed by the earlier workers and they attempted to explain this phenomenon by proposing a bridge model for the thorax. The model was not developed sufficiently and the arms of the bridge were left undefined. A close examination of the system showed that such a model for thorax cannot be unique (i.e. the arms of the bridge cannot be defined uniquely) and there will be a certain amount of arbitrariness in assigning various portions of the thorax to different arms. The study revealed that for explaining the genesis of FPG, the thorax can be considered to be a series combination of three impedances which can be defined in a unique manner with the help of equipotential surfaces (obtained from the numerical models developed earlier) through the pick-up electrodes. This series model helped in showing how the respiratory interference is minimized and also gave rise to a condition which has to be satisfied if respiratory component is to be absent in the FPG output. The model also indicated the usefulness of a voltage source for excitation in FPG and provided a general guideline for selection of excitation sources. It has been proved with the help of this model that FPG is more sensitive to cardiac activity compared to IPG. It has also been shown that contrary to IPG, the FPG technique does not measure any impedance but provides a dimensionless quantity which is determined by the ratio of two impedances. Thus, this study has provided a fundamental understanding of the genesis of FPG.

Although emphasis has been placed in this thesis on developing an understanding of the FPG technique through theoretical studies, few experiments were also carried out with human subjects, both diseased and normal, to establish the physiological correlates of the FPG waveform. FPG instrument was designed and fabricated in the laboratory and recordings were taken with normal and diseased subjects. The study showed that a typical waveform could be identified for normal subjects. The waveform was slightly affected by the posture of the subjects whereas its amplitude changed appreciably. Experiments in a Catheterization Laboratory helped in associating the two peaks in FPG with the beginning of ventricular ejection and filling respectively. Examination of the waveforms obtained from diseased subjects showed a characteristic feature in all subjects with aortic regurgitation. Thus FPG has a possible diagnostic application. The studies also confirmed the conclusions drawn from the analytical and numerical investigations. It has been concluded that FPG holds a high promise as a useful tool for cardiac monitoring.

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