New Trends in Balistocardiography

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Abstract. *Balistocardiography is a method by which body vibrations caused by heart activity are registered. Evolution during the past fifty years to the present is described. Balistocardiography (BCG) represented by instruments of different natural frequencies and damping should bring information about cardiac output. This expectation was not fulfilled due to the unsuitable physical properties of apparatuses. Quantitative balistocardiography (Q-BCG) was based on the exact physical properties of the newly-developed apparatuses, force acting and force registered were exactly measured and expressed in units of force in Newtons. Quantitative seismography (Q-SCG) opens a new field of cardiovascular dynamics examination. Force applied is registered without amplitude, phase or time distortion. Using this absolutely non-invasive method, a new field of monitoring heart rate variability was opened up. Systolic force as well as heart rate variability in relation to changes in external stimuli are registered. Quantitative seismocardiography probably offers a more complex view of both inotropic and chronotropic heart functions. It will be suitable for: examining operators exposed to stress; for assessing the effect of work, fatigue and mental stress; for monitoring persons as part of disease prevention; for determining a person's ability to carry out their duties both on the ground and in the air.*

Keywords: Quantitative Balistocardiography (Q-BCG), Quantitative Seismocardiography (Q-SCG), Heart Rate, Non-invasive Cardiovascular Methods

1. Introduction

In balistocardiography body vibrations caused by the heart activity are registered. Balistocardiography is a non-invasive method enabling the examination of the cardiovascular dynamics.

This field has a longer history than is commonly known. William Harvey (1578-1657) who discovered blood circulation called his work, published in 1628, „Exercitatio anatomica de motu cordis et sanguinis in animalibus." As the title suggests, this work covers two main topics:

a) movement of the heart
b) movement of the blood

Harvey also states that movement is one of the basic functions that sustain circulation. This process requires impulse and force (impetus et violentia), which are produced by the heart (impulsor). The heart itself may „produce force and impulse", while blood is propelled and forced to "leave its source and home" towards the peripheral parts of the body.

One of our notable specialists in internal medicine, Josef Škoda (1805-1881), published in 1837 his work "On the heartbeat and heart murmurs caused by cardiac movement". He compares the heartbeat with a gun's recoil and Segner´s water-wheel.

2. Methods and Results

Balistocardiography (BCG)
In 1936, Starr took part in a conference held by the American Society of Physiology which dealt with methods of determining cardiac output. For this purpose, he used a bed with tight springs, whereby by the movement against these springs increased the instrument's natural frequency to values higher than the heart rate. Thus began the era of high-frequency balistocardiography, which lasted approximately 15 years. Other types of instruments were developed later on which measured the displacement, velocity or acceleration of a body lying on a bed. Later studies showed that there are difficulties when comparing records registered on different apparatuses. This is mainly caused by two factors:

a) the instrument's natural frequency
b) the instrument's damping

The instrument's natural frequency lies within the range of the frequencies caused by the cardiac activity that we wish to observe. This leads to interference and the subsequent recording is a summation of the oscillations of the instrument and those of the heart. The other factor that significantly affects the shape of the registered curve is the damping installed in these instruments (which are basically oscillatory systems) in order to prevent the periodic oscillations of the instruments themselves. Records of heart activity are therefore deformed.

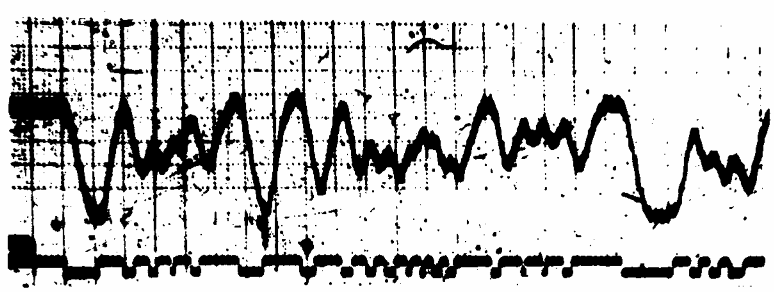

Fig. 1. Records registered using the BCG instrument with a frequency of 2Hz and critical damping. The lower curve depicts the effect of force applied, which is still of the same intensity but differs in the duration of its effect. The upper curve is a record, from which one cannot determine either size or duration of the acting force.

Quantitative balistocardiography (Q-BCG)
Following the critical evaluation of all these facts, we began in 1952 our own experiments related to the construction of an apparatus which would lack the aforementioned shortcomings. Thus, over the years, we constructed an apparatus whose advantages lie not only in the simplicity of its design, but also in its important functional qualities.

The properties of the pick-up device and bearing structure, the subject's sitting position in close contact with the seat and an amplifier with a sufficiently long time constant reduce the possibility of shape, phase and time deformation of the records. All this enabled us to conduct a physical and mathematical analysis of the balistocardiographic system and to calibrate our instrument. Based on these processes, we designated our apparatus a quantitative balistocardiograph. This was chiefly to distinguish it from previous instruments that registered displacement, velocity and acceleration and were designed to determine cardiac output on one hand, and also because our instrument was calibrated so that force expressed in Newtons registers an amplitude measurable in mm, whereby the relationship between the size of the active force and the registered amplitude is linear, on the other hand. Our quantitative balistocardiographic method enabled us to introduce two characteristic quantities: systolic force (F) and minute cardiac force (MF), thus using quantitative balistocardiography in an exact manner when studying cardiovascular dynamics at rest and during stress.

Current applications of Q-BCG: In papers published to date we drew on the fact that the relationship between the force acting on the pick-up device and the amplitude of the balistocardiographic curve is linear. This enabled us to study the evolution of systolic force in relation to age and ageing, the influence of hypoxia and hyperoxia. We were also able to follow the changes in Q-BCG indices at rest and under workload in various groups of volunteers, and to determine the linear relationship between the skeletal muscle force and systolic force, and determine changes in Q-BCG indices in various pathological states. We also compared our parameters, determined by Q-BCG, with parameters determined using other non-invasive methods.

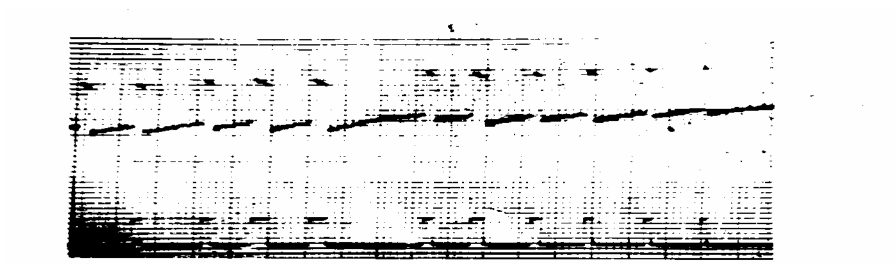

Fig. 2. Record registered using the Q-BCG apparatus. The lower curve depicts the effect of force applied, which is still of the same intensity but differs in the duration of its effect. The upper curve is an exact recording of the size and duration of the acting force.

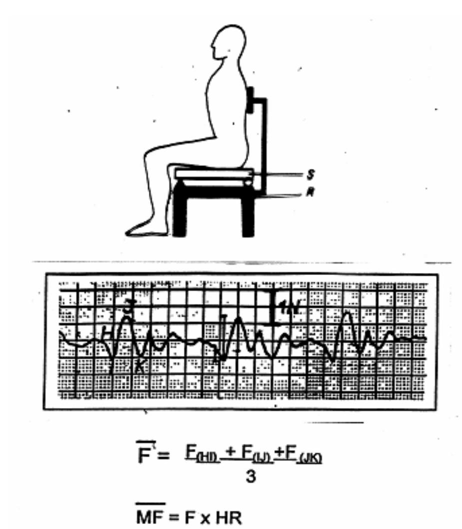

Fig. 3. Quantitative Balistocardiography (Q-BCG)

Quantitative seismocardiography (Q-SCG)

During a visit to the Flight Psychophysiology Laboratory at Wright-Patterson Airforce Base, a new application field for Q-BCG emerged. This made use of the fact that our method enables the recording of force applied without phase or time deformation. Thus, heart rate may be monitored and analysed using the method of heart rate variability. The method of Q-BCG was designated by the laboratory employees as absolutely non-invasive, as the persons examined did not have any electrodes attached to the body surface and were not connected by cables to the registering instrument. This new field of monitoring heart activity, whereby we determine both amplitude-force and time-frequency relationships, is termed quantitative seismocardiography. Thus, one may determine the force-response of the cardiovascular system to changes in external stimuli, as well as the autonomous nervous system regulation of the circulation and the activity of the sympathetic and parasympathetic systems.

3. Discussion and Concluions

Quantitative seismocardiography probably offers a more complex view of both inotropic and chronotropic heart function. It will be suitable for: examining operators exposed to stress; for assessing the effect of work, fatigue, mental stress; for monitoring persons as part of disease prevention; for determining a person’s ability to carry out their duties both on the ground and in the air.

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