CALIBRATED PHONOCARDIOGRAPHY

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Since the early days of phonocardiography (PCG)* the clinical value of calibration of the record has been a controversial subject. Some have asserted that calibration of the PCG is impracticable[1] or useless.[2] Others have held that calibration of the record yields additional information of clinical value.[3-5] According to McKusick, 'Phonocardiography attains its highest precision and greatest physiologic usefulness when quantitation is applied in each of the three parameters of heart sounds'.[6] These parameters are timing, frequency, and intensity.

The main argument against calibration of the PCG is that loudness of the heart sounds and murmurs at the chest wall depends not only on cardiac activity but also on the position of the heart and the state of the tissues between the heart and the surface of the body. In spite of this limitation, physicians have laid stress on the loudness of heart sounds and murmurs as being of clinical significance. Levine[7] classified cardiac murmurs in 6 degrees of loudness and noted that all but the faintest are usually of pathological significance.

Physical Considerations

Although heart sounds and most murmurs are not pure tones, it is possible to analyse their wave form. The heart sounds have frequencies of the order of 25 - 100 cycles per second (c.p.s.).[8] Murmurs consist of sound waves with frequencies in the range 120 - 660 c.p.s.[9] Most of the sound phenomena detected by cardiac auscultation or PCG have frequencies below 650 c.p.s.[10,11] Within the range 25 - 500 c.p.s. the loudness of a sound varies as the product of the square of the amplitude and the square of the frequency. Heart sounds vary little in frequency but the loudest heart sounds may be as much as 40 times greater in amplitude than the faintest.[12]

A PCG should incorporate a filter to eliminate vibrations below 15 c.p.s., which would otherwise mask the record of audible phenomena.[13] Filters are employed, also, either to simulate the progressive increase in sensitivity of the human ear up to 500 c.p.s. (logarithmic PCG[14]) or to isolate selected frequency bands for recording.[15] In either case a standard sound signal or an electrical signal corresponding to some appropriate sound may be passed through the amplifier at the same gain and filter settings, and recorded on the PCG. The amplitude of vibration of the heart sounds and murmurs may then be compared with that of the standard signal.

Methods of Calibrated Phonocardiography

An early attempt at PCG calibration was made by Hess,[16] who used a tuning fork set into vibration by a standard deflection at a standard distance from the chest-piece of his apparatus. The amplitude of heart sounds and murmurs was compared with that of the record of the vibrations of the tuning fork.

Mannheimer[3,15] calibrated a microphone, using the pistonphone technique that has subsequently been used by other investigators.[17,18] When the sensitivity of the microphone has been established in absolute units (mV output/dynes per sq. cm. sound pressure applied to microphone) it is convenient to use an electrical signal corresponding to a particular frequency and intensity of sound applied to the microphone rather than the sound signal itself. Piezo-electric crystal microphones retain their sensitivity for at least 2 years if carefully handled.[19]

Wells[17] and McGregor,[5] with their colleagues, recorded at the end of each PCG a signal corresponding to a standard sound at 500 c.p.s. and 80 decibels (db) above an arbitrary threshold of audibility. Counihan and his associates[20] increased the standard signal to 90 db above this threshold. Besterman and Harrison[21] and Sloan and Greer[4] recorded a 50-cycle signal. Dunn and Rahm[18] used a signal at 100 c.p.s.

Luisada and Gamna[22] applied a sound signal at 100 c.p.s. to the patient's chest at 10 cm. from the microphone of a Sanborn twin-beam PCG and recorded this signal as well as the standard electrical signal provided by the instrument.

Two modified PCG techniques that fail to record the actual sound waves but give an indication of their intensity have been developed in recent years. *Sonvelography*[23] employs a direct-writing instrument to record an 'envelope' of the intensity of heart sounds during the cardiac cycle. In *spectral phonocardiography*[24] the output from the microphone is filtered into selected frequency bands; the horizontal axis of the record represents time, the vertical represents frequency, and the intensity of the record in each frequency band indicates sound amplitude at that frequency.

A SIMPLE CALIBRATION DEVICE

The calibration device shown in Fig. 1 is a simplified ver-

*The initials PCG are used for the phonocardio-graph, -graphy, -graphic and -gram.

sion of that previously described by Sloan and Greer.[4] It is inexpensive to make and easy to fit to any electronic PCG. The present model has given satisfactory service for 4 years. The PCG employed is a Cambridge 4-channel recording apparatus (type 72111B) employing piezo-electric crystal microphones, valve amplification, and mirror galvanometers. Heart sounds, jugular phlebogram, electrocardiogram, and respiratory movements, are recorded simultaneously. In this, as in most modern PCGs a stable source of low-voltage alternating current (50 c.p.s.) is readily available; failing such a source a filament transformer may be used from an a.c. mains supply. From the input signal (3 - 6 volts) the appropriate voltage is selected by means of the variable resistor to give an output corresponding to the output from the microphone at a particular sound level. The reading in volts on the voltmeter corresponds to the signal strength in millivolts fed into the amplifier. Usually a signal corresponding to a sound pressure of 25 db above the auditory threshold is appropriate, taking the threshold at 50 c.p.s. as 0·35 dynes per sq. cm.[25]

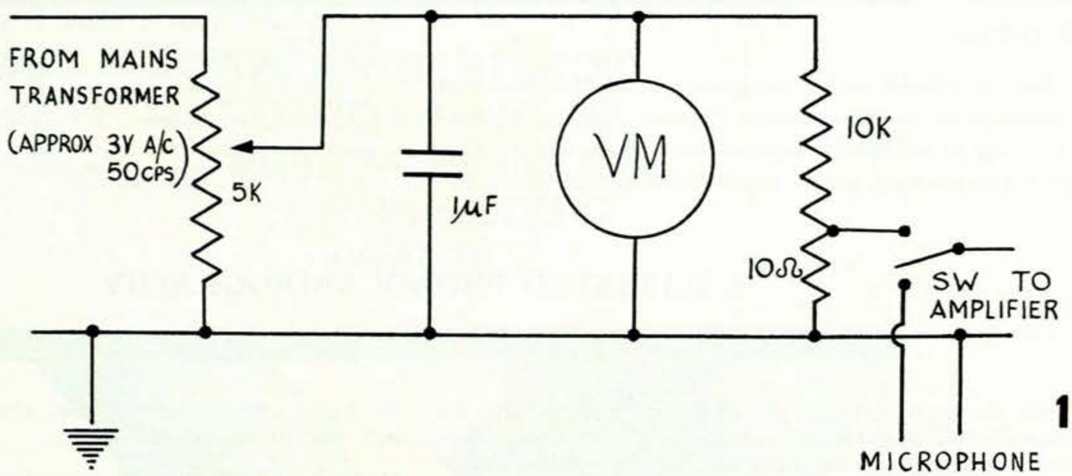

Fig. 1. Circuit diagram of calibrator. Resistor values in Ω (ohms) and K(10^3ohms); µF=microfarads; V=volts; VM=voltmeter (O - 3v); SW=switch.

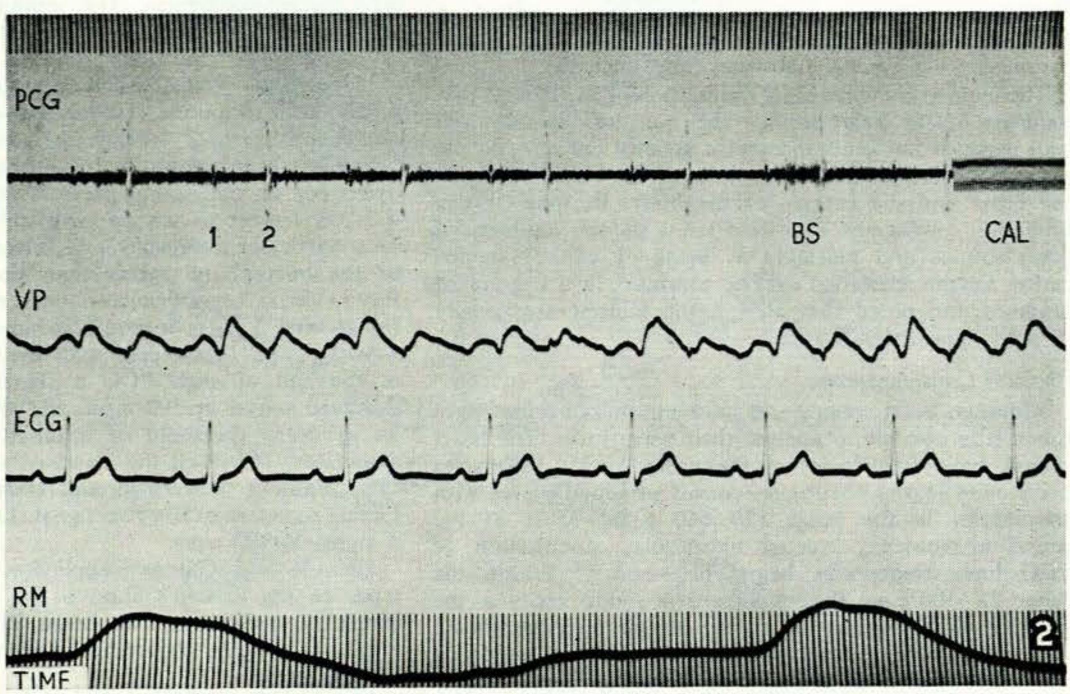

Fig. 2. Calibrated phonocardiogram. PCG=normal apical phonocardiogram (high-frequency channel); 1, 2=heart sounds; BS=breath sound; CAL=calibration signal (25 db above auditory threshold); VP=venous pulse (jugular phlebogram); ECG=electrocardiogram (lead II); RM=respiratory movement (upstroke=inspiration). TIME in 1/25 sec.

In practice the calibration procedure is very simple. At the end of each recording of heart sounds a push-button switch is depressed for a few seconds; this cuts out the microphone and feeds into the amplifier the standard sound signal instead. The standard signal, at the same gain and filter settings as the record of the heart sounds, is recorded on the tracing and the amplitude of the sounds may be compared with that of the standard signal (Fig. 2).

Discussion

Although a number of useful proposals regarding the standardization of PCG were adopted at international cardiological meetings in 1953[26] and 1956,[27] the problem of calibration has not yet reached the stage of international agreement.

Since the amplitude of the loudest heart sounds is much greater than that of the faintest, the gain of a phonocardiograph amplifier must be varied from one patient to another if the maximum efficiency of the instrument is to be exploited. Some indication of the gain employed is of value in correlating PCG with auscultatory findings, since with a high gain the PCG may reveal sounds or murmurs that were inaudible, and a low gain, which may be necessary to record the full amplitude of loud sounds, may result in failure to record sounds or murmurs that are clearly audible.[4]

Since the heart sounds have fundamental frequencies in the range 25 - 50 c.p.s. and few overtones, their absolute loudness can conveniently be calculated by reference to the amplitude of the standard sound signal. The criterion of intensity of sound on the PCG may be either (1) the amplitude of the largest wave, (2) the mean amplitude of the waves (assessed by scanning), (3) the mean amplitude of the waves (calculated from measurement of each wave), or (4) the area enclosed by the waves. The first of these standards is the simplest and the most useful.[28]

The higher frequency of murmurs makes assessment of their absolute loudness by comparison with a 50 c.p.s. signal more difficult but, on a logarithmic PCG, which simulates the varying sensitivity of the human auditory mechanism to different frequencies of sound, the comparison of the record of the murmur with the record of the standard sound signal is still a useful one. If the deflections corresponding to the murmur exceed in amplitude the deflections corresponding to the standard signal, the murmur should be audible. The high-frequency channel of the Cambridge PCG gives a record corresponding approximately to a logarithmic PCG and capable of the same interpretation.

The microphone should normally be recalibrated annually, but additional recalibration is necessary after it has been subjected to any sudden impact. Calibration requires a pistonphone device, obtainable in an acoustic laboratory, or the microphone may be calibrated against another already calibrated in absolute units. Even without calibration of the microphone a standard signal recorded on the PCG is of value in comparing the relative loudness of sound phenomena on different records, but it is obviously desirable to be able to express the loudness of the sounds, or at least that of the standard signal, in absolute terms.

SUMMARY

Calibration of a PCG is simple to perform and adds useful additional information to that obtained from the uncalibrated record. Different methods of indicating sound intensity on records of heart sounds and murmurs are discussed and a simple calibrator is described, which may be fitted to any electronic PCG. A standard signal is recorded at the end of each PCG; the loudness of heart sounds and murmurs is then assessed by comparing the amplitude of their deflections on the record with the amplitude of deflection of the standard signal.

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