The Korotkoff Sound

G. M. Drzewiecki
Department of Biomedical Engineering
College of Engineering
Rutgers University

J. Melbin and A. Noordergraaf
Cardiovascular Studies Unit
Departments of Bioengineering and Animal Biology
University of Pennsylvania

(Received 2/17/88; Revised 11/2/88)

As the auscultatory method of blood pressure measurement relies fundamentally on the generation of the Korotkoff sound, identification of the responsible mechanisms has been of interest ever since the introduction of the method, around the turn of the century. In this article, a theory is proposed that identifies the cause of sound generation with the nonlinear properties of the pressure–flow relationship in, and of the volume compliance of the collapsible segment of brachial artery under the cuff. The rising portion of a normal incoming brachial pressure pulse is distorted due to these characteristics, and energy contained in the normal pulse is shifted to the audible range. The pressure transient produced is transmitted to the skin surface and stethoscope through deflection of the arterial wall. A mathematical model is formulated to represent the structures involved and to compute the Korotkoff sound. The model is able to predict quantitatively a range of features of the Korotkoff sound reported in the literature. Several earlier theories are summarized and evaluated.

Keywords—Korotkoff sound, Blood pressure measurement, Auscultatory method.

INTRODUCTION

Rudiments of the auscultatory method of blood pressure measurement can be traced to Vierordt (63) and Marey (44). In 1855 Vierordt offered what was probably the first method of noninvasive measurements of blood pressure capable of providing some quantitative information, by means of known weight applied to the arterial pulse. Pulse obliteration remains an essential element of the current method.

Application of weights could not be related to blood pressure easily. To eliminate this problem Marey (44) enclosed the arm in a sealed chamber, thereby applying a known level of uniform fluid pressure. Later, Riva-Rocci (56) replaced Marey's arm chamber with the more convenient arm cuff.

Address correspondence to G. M. Drzewiecki, Department of Biomedical Engineering, College of Engineering, Rutgers University, Piscataway, NJ 08855-0909.
In 1905, Korotkoff (37), a Russian army physician, reported on the use of a stethoscope in conjunction with an occlusive cuff. In experiments on the collateral circulation in a limb of a dog, Korotkoff noticed that sound could be detected just distal to a pressurized cuff, but only if the collapsed artery is forced open by an incoming pulse. Korotkoff argued that lumen opening must occur when peak arterial pressure just exceeds cuff pressure, thereby introducing a new means of blood pressure determination. This procedure became established as the auscultatory method of blood pressure measurement. Currently, the American Heart Association recommended procedures for its use (36). In brief, the technique is applied as follows: A cuff is wrapped around the upper arm, and the cuff pressure is quickly raised to about 30 mmHg above the level of pulse obliteration. Then, cuff pressure is released at the rate of 2-3 mmHg/sec. The first Korotkoff sound heard in the stethoscope is similar to a faint tapping. It is referred to as the phase I sound. As the cuff pressure continues to fall, the sound first becomes louder, goes through a maximum (Phase III), then gradually diminishes and changes character. When the sound becomes muffled it is referred to as the phase IV sound. Further decreases in cuff pressure cause the sound to disappear entirely. The last heard is referred to as phase V. The occurrence of phase I is interpreted as cuff pressure being equal to systolic arterial pressure and either phase IV or phase V as equal to diastolic arterial pressure.

Comparison with direct blood pressure measurements, carried out by London and London (41), revealed that the accuracy of the auscultatory method is rather limited. Typical mean errors of −5 to −20 mmHg in systolic pressure and of +12 to +20 mmHg in diastolic pressure were found. Automated sphygmomanometers that are based on the auscultatory method offer no improvement in accuracy over the human observer (66).

The accuracy of the auscultatory method can be compromised by several factors, which may be categorized as: (a) Cuff size (60), (b) Observer precision and auditory acuity, (c) Choice of phase IV or V for diastolic pressure, (d) Manometer accuracy, (e) Cuff deflation rate, (f) Arm elevation and posture (hydrostatic pressure effect), and (g) Vascular tone in the arm distal to the cuff (23,50,53,70).

In the auscultatory method of blood pressure, three functional components may be identified. These are: (a) Cuff pressure transmission to the artery, (b) Korotkoff sound genesis, and (c) Sound transmission to the ear. Of these three, cuff pressure transmission to the artery was analyzed by Alexander et al. (1), and transmission of sound to the ear by Drzewiecki et al. (18,22) and Rabbany et al. (52). The least understood component remains the origin of the Korotkoff sound. As a consequence, most of the effects that influence the accuracy of blood pressure readings remain to be clarified. This report offers a quantitative interpretation of the phenomena held responsible for the origin of the Korotkoff sound.

THEORIES ON THE ORIGIN OF THE KOROTKOFF SOUND

It has long been appreciated that the key to a better understanding of the operation of the auscultatory method lies in the identification of the mechanism responsible for the origin of the Korotkoff sound. Accordingly, attempts have been made to identify this mechanism and several theories have resulted. These will be reviewed and evaluated in this section.

For the purpose of discussion, theories for the origin of the Korotkoff sound have