The Significance of the Intermediate Korotkoff Sounds

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Except for those sounds that mark the systolic and diastolic blood pressure levels, the murmurs during sphygmomanometry are generally ignored. Our studies suggest that the intensity and duration of these murmurs provide an appraisal of the blood flow into the part beyond the cuff under certain conditions.

The sounds heard at the brachial artery distal to the point of compression by the sphygmomanometer cuff have been classified into several phases. As the cuff pressure falls from high levels, the onset of a snapping sound characterizes the level of the systolic pressure. With further reduction of the pressure in the cuff the sound changes through an assortment of murmurs and rumbles until finally it becomes muffled and then disappears entirely. The diastolic pressure has been variously designated as related to the sudden marked change in tone as the cuff pressure continues to fall or to the complete disappearance of the brachial sounds. Since the sounds intermediate between the systolic and diastolic levels have not been equated with any specific physiologic event or clinical determinant, they are ordinarily ignored during the blood pressure determination.

Our studies on flow through collapsible vessels suggested that the Korotkoff sounds may depend on the occurrence of flow in the arteries under the cuff, with the production of a fluttering of the vessel walls. If this proved true, attention to the intensity and duration of the intermediate sounds would provide an index of blood flow to the extremity beyond the cuff. To test this hypothesis we undertook studies on patients and on artificial circulation models.

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Clinical Survey

Preliminary studies were carried out on 75 volunteers and patients on the wards of the Michael Reese Hospital. The essential experiment was carried out as follows: A blood pressure cuff was placed over the upper arm and a stethoscope bell was placed over the brachial artery at the antecubitus. The blood pressure was then taken according to the standard technics and criteria of the American Heart Association. Records were made not only of the systolic and diastolic levels but, when they were clearly heard, of the time of appearance of the intermediate rumble and of the sudden change in tone auguring the diastolic level.

The intermediate rumble usually became audible at a level 5 to 10 mm. Hg below the onset of the snapping systolic sound. It often became intensified as the cuff pressure decreased and occasionally split into a double sound. The rumble then waned and changed suddenly to a soft blowing sound, heralding the diastolic level. At a level only 5 to 15 mm. Hg below this level the sound usually disappeared entirely.

The loudness and intensity of the rumble was notable in all male subjects tested. In some patients the intermediate sounds could be heard only with difficulty. They were often absent or barely discernible especially in non-gravid women. They were easily heard in women in the last trimester of pregnancy.

These data lend themselves to the interpretation that the intensity of the intermediate Korotkoff sounds was related in some way to the volume of blood flow to the distal portion of the extremity. In men with good muscular
development of the forearm, the blood flow supplied to this part is greater than in women with lesser muscular development. In pregnant women, generalized vasodilatation is the rule, the extremities apparently sharing in the increased cardiac output. To test this interpretation, experiments were designed to induce an increased or decreased flow through the arm distal to the cuff.

Effect of Reactive Hyperemia and Tourniquet upon Arteriophonograms

In 15 subjects the Korotkoff sounds were recorded by means of a Cambridge phonocardiographic apparatus. The intensity and duration of the sounds were recorded as the cuff pressure fell from above systolic to less than diastolic (fig. 1, C). These records made it possible to analyze the sounds objectively after maneuvers affecting blood flow to extremities.*

* The aural interpretation of intensity of a sound is due to a combination of amplitude of vibration, duration and frequency spectrum. This is particularly true in sounds of short duration as may occur in the Korotkoff or heart sounds. Graphic recording with standard phonocardiographic equipment provides a measure of the duration of the sound but does not always give an entirely adequate representation of the frequency-time spectrum or of the subjective interpretation of “intensity.”

A simple procedure was used to induce reactive hyperemia. The pressure in the sphygmomanometer cuff was raised above the systolic pressure (250 mm. Hg) in order to obstruct the blood flow beyond the cuff. The patient was then directed to open and close the fist of the affected arm 50 times in about 35 seconds. The cuff pressure was then allowed to fall as in the usual blood pressure determination. This procedure had no effect on the systolic and diastolic pressures, but the intermediate rumble was markedly intensified and prolonged in all instances (fig. 1, E).

Observations were also made on the Korotkoff sounds during obstruction to flow through the arm. For this purpose, a tourniquet cuff was placed immediately distal to the stethoscope bell. This tourniquet cuff was then inflated to 250 mm. Hg. Blood pressure determinations were then made as usual. The tourniquet procedure had no effect on the systolic and diastolic pressures, but in all instances the intensity and duration of the Korotkoff sounds were markedly diminished (fig. 1, T).

Model Experiments

Further studies were undertaken on a model utilizing a segment of soft-walled Penrose tubing as an “artery” (fig. 2). The “artery”

![Fig. 1. Phonoarteriograms obtained on a normal subject. Record C (control) shows the sounds recorded in a resting subject while the cuff pressure was permitted to fall rapidly as noted in the calibrations given in millimeters of mercury at the bottom of the figure. Time is in 0.04 second.

Record E (exercise) was obtained after the sphygmomanometer cuff pressure had been raised and kept at 250 mm. Hg for 35 seconds, with the fist being opened and closed 50 times in this time period. Note the increased intensity and duration of the Korotkoff sounds in this reactive hyperemic period, compared with the control.

Record T (tourniquet) was obtained when a tourniquet was in place immediately distal to the microphonie pickup. Note the marked diminution in intensity and duration of the Korotkoff sounds in this period of reduced flow, compared with the control. (Discussed in text.)
was enclosed in a glass chamber so that it could be partially compressed by applying air pressure by means of a sphygmomanometer bulb. The cuff pressure was measured with a manometer attached to a side arm of the glass chamber. The arterial pressure was provided by maintaining a column of water at a fixed level above the artery.

The pressure in the cuff was then raised above the level of the supply reservoir. A small but definite volume of water flowed through the "artery," the amount depending on the level of the cuff pressure (fig. 3).

The cuff pressure was then permitted to fall steadily. When the cuff pressure was exactly equal to the lateral pressure at the inlet tube to the elastic segment, the walls of the "artery" began to vibrate, producing an audible murmur and a palpable thrill. Observation of the segment by stroboscope or high speed cinematography revealed a regular fluttering of the wall at rates varying from 20 to 100 per second.

The production of sound was absolutely dependent on the occurrence of flow through the artery (fig. 4). The intensity of the sound was associated with the height of the supply reservoir. When the flow was increased, as could be done by providing a higher "arterial" pressure, the intensity of the sound was also increased. When flow was stopped the sound also stopped. The frequency of flutter, and the fundamental pitch of the sound, were dependent on the cuff pressure, that is, upon the degree of compression of the elastic segment. As the cuff pressure was permitted to

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**Fig. 2.** Diagram of model employed. Flow takes place under a driving head, A, through a rigid tube to the "arterial" segment, B, and then out through the rigid portion, C. Cylinder D encloses the segment ABC. E are rubber stoppers inserted into each end of cylinder, D, with holes permitting tubes A and C to pass through. F is a syringe bulb used to increase pressure in the glass cylinder chamber, the pressure being indicated in manometer G. (Discussed in text.)

**Fig. 3.** Flow through the elastic segment illustrated in figure 2. Flow is maintained by a driving head arranged to provide a lateral pressure of 120 cm. H₂O at the inflow to the "artery." Vertical axis represents cuff pressure (sphygmomanometer) in centimeters of water. Horizontal axis gives flow in milliliters per second. The numbers on the curve represent the fundamental frequency of flutter of the "artery" at different degrees of compression indicated by the vertical axis. This value was obtained with the use of the stroboscope. When cuff pressure is higher than driving (arterial) pressure, a small flow occurs, but no murmur is produced (flutter frequency equals zero). When cuff pressure falls below lateral pressure, flow continues to increase, but at a different slope, and the murmur is heard with fundamental frequencies indicated by the numbers alongside the curve. At a critical lower cuff pressure the murmur suddenly ceases. Below the critical value, cuff pressure has little effect on flow. (Discussed in text.)
fall, a critical level was reached, usually about 20 cm. H₂O, below which the murmur and thrill ceased abruptly.

**Discussion**

When the auscultatory method of blood pressure determination was first described by Korotkoff, many attempts were made to explain the mechanism of the sounds. These explanations have included attributing the sounds to the passage of the blood pressure wave, causing the opening of the compressed artery and producing a slapping tone, to water-hammer pulses, to vibrations produced by a change in the form of the compressed vessels, to conversion of the compressed area of the arm into a resonating mass, and to together, and the degree of constriction increases. The velocity of the stream through the constricted area increases further, the lateral pressure is reduced still more and the process of constriction becomes more marked. This continues until the vessel is almost entirely closed. At this point, velocity drops toward zero and all the energy of the column becomes available as lateral pressure. The walls of the constricted portion are then momentarily blown apart. Then the process of increased velocity with its progressive constriction begins again and the cycle is repeated. These flutterings of the walls are suggested as the mechanism of production of murmurs and palpable thrill. When the cuff pressure is above arterial pressure, a slight flow takes place but no flutter is produced.

![Fig. 4. Phonogram obtained in model experiment. The horizontal white bars show two periods during which water was permitted to flow through the elastic segment of the apparatus described in figure 2. Flow was obstructed in the intermittent periods. Time is in 0.04 second. Sound is noted in the upper tracing shortly after flow begins and disappears shortly after flow ceases. (Discussed in text.)](image)

waves reflected from the point of occlusion. Other factors have been implicated in the production of the sounds heard in sphygmomanometry, including turbulence, impact and recoil.

Our present results suggest that the flutter mechanism with the production of murmurs and thrills is derived from the operation of the law of conservation of energy. In brief, this law states that the energy of a volume of fluid may be considered to be the sum of the energy expressed as lateral pressure, plus the kinetic energy of movement. As applied to the artery under the cuff, the following events take place: The artery is partially constricted by the pressure in the cuff. As blood flows through the stenotic portion, its velocity must increase. The increase in velocity results in a reduction in lateral pressure energy at the constricted site. In consequence, the lateral pressure at this point falls, the walls tend to move closer

When cuff pressure has fallen to levels at which no stenosis is produced, flutter is again absent since there is no site of high velocity flow.

In the case of sphygmomanometry the fluttering is probably produced at the site of partial constriction of the artery underneath the cuff. The flow through the arterial segment under the cuff, when arterial pressure is greater than cuff pressure, is presumed to throw the walls into flutter producing the Korotkoff sounds. The experiments with the model suggest that the greatest flutter activity occurs at the distal end of the artery under the cuff. This may account for the fact that the sounds are loudest at this point.

The present study suggests that the duration and intensity of the Korotkoff sounds are related to flow through a segment of collapsible vessel. Reduction of flow produced by placement of a tourniquet beyond the point of auscultation results in a diminution or even
elimination of the sounds. An increase in the volume of flow brought about by the production of a reactive hyperemia causes an intensification and prolongation of the murmurs. Similar effects can be illustrated repeatedly in the model. The intensity and duration of the Korotkoff sounds, therefore, may be considered to provide a rough, but perhaps useful, appreciation of the volume flow through the arteries under the cuff. This volume blood flow depends, of course, on the resistance to flow through the vascular bed of the extremity, provided arterial pressure is constant.

In other studies we have demonstrated that a rough index of flow through peripheral arteries can be obtained by appropriate analyses of oscillometric pulsations. A combination of the technic described in the present communication and that utilizing oscillometric pulsations may provide a simple clinical appraisal of flow through the vessels of the extremities, or, conversely, of the peripheral resistance provided by the vascular bed of the extremity. This may perhaps be achieved by noting simultaneously the intensity of the murmurs and the oscillations of the sphygmomanometer mercury column or aneroid indicator.

Summary

Conditions favoring blood flow (reactive hyperemia) through the arteries under the sphygmomanometer cuff increased the intensity and duration of the sounds heard during auscultatory measurement of the blood pressure. Conditions reducing flow through the arteries under the cuff, as by the application of a tourniquet distal to the stethoscope pickup, decreased the intensity and duration of these sounds. The murmurs heard over the artery are shown to be produced as a result of the dynamic pressure-velocity relationships resulting from partial constriction of the vessels by the cuff pressure. The intensity and duration of the Korotkoff sounds, therefore, can be used to appraise the blood flow into an extremity.

Sumario Español

Excepto por los sonidos que indican los niveles de presión sistólica y diastólica, los ruidos presentes durante la esfigmomanometría son generalmente ignorados. Nuestros estudios sugieren que la intensidad y duración de estos ruidos proveen un estimado de la circulación de sangre a la parte distal de la banda pneumática bajo ciertas condiciones.

References

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