The Significance of the Intensity and Time of Appearance of the Korotkoff Sounds in Auricular Fibrillation

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Aside from their value in the indirect determination of the blood pressure the sounds at the brachial artery provide other valuable clinical information. Their value in blood pressure determination in auricular fibrillation generally has been found to be limited. By using a simple technic involving the counting of the brachial-artery-sound deficit, a satisfactory, repeatable method of blood pressure estimation is achieved in such patients with marked pulse rate irregularities. Other information, including a rough estimation of left ventricular stroke output, pulse wave force and velocity, are also appraised by analysis of these bruits.

Aside from their common use for estimation of the blood pressure level,1 the Korotkoff sounds also provide other useful clinical information. Thus, the intensity and duration of the sounds provide an appraisal of the volume of blood flowing through the artery under the cuff.2 A calibrated contour of the upstroke of the pulse wave, as well as an estimate of the celerity of its transmission rate, can also be established.3

The present study provides evidence that the time of onset of the sounds during the cardiac cycle is related to the diastolic filling time. In auricular fibrillation the determination of the incidence of the sounds at various cuff pressure levels permits a satisfactory measure of the blood pressure level despite irregularities of the pulse.

METHODS

The sounds at the brachial artery were recorded simultaneously with lead II of the electrocardiogram in seven patients with auricular fibrillation. The pressure in the sphygmomanometer cuff was first raised to levels higher than systolic in order to occlude blood flow to the extremity. The patient was then instructed to open and close his fist 30 times in order to induce a reactive hyperemia of the limb. The pressure in the cuff was then permitted to fall at a constant rate. In other experiments it was lowered by increments of 10 mm. Hg, and 10 to 20 cardiac cycles were recorded at each of these pressure levels.

Each cycle length was measured as the R-R interval. The time of arrival of the sound in each cycle was measured and this value was compared with the duration of the previous cycle. The logarithmic intensity and duration of the sound were determined directly from the photographic record as millimeters of swing of the galvanometer.

RESULTS

(1) Effect of Cuff Pressure on the Ratio of the Incidence of Korotkoff Sounds to that of the R Waves. The ratio of the incidence of the Korotkoff sounds to the number of electrocardiographic cycles provided a satisfactory means for a blood pressure determination (fig. 1). At sufficiently high cuff pressures, no sound was heard or recorded. As the cuff pressure was lowered by increments from these high levels in a given patient, a point was reached at which occasional sounds could be heard and then the ratio of Korotkoff sounds (K) to electrocardiographic QRS complexes (R) increased rapidly. Within a range of about 10 mm. Hg, the K/R ratio increased from zero to about 50 per cent. A further drop of cuff pressure of 10 or 20 mm. Hg increased the ratio usually to about 90 per cent or more; i.e., 9 of each 10 electrocardiographic complexes were followed by Korotkoff sounds.

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level in patients with marked cardiac arrhythmias.

(2) Relation of Preceding Cycle Length to the Incidence of the Korotkoff Sounds. The likelihood of occurrence of the Korotkoff sounds obtained at each given cuff pressure level correlated well with the duration of the preceding cycle. Thus, when the preceding length was less than 0.40 second, no Korotkoff sound was heard in the immediately succeeding beat. For preceding cycle lengths ranging between 0.42 and 0.48 second the sounds were heard irregularly. It is likely, though our data are insufficient to establish this, that the incidence of occurrence of the sounds increases in a regular fashion with the length of the preceding cycle length in this range. When the preceding cycle lengths were 0.50 or more, a sound was always heard.

(3) Relationship of Amplitude of Sound to Previous Cycle Length. The amplitude of the sounds could be correlated grossly with the duration of the previous cycle. This is illustrated by the data presented in figure 2, obtained in a single continuous run on a patient with fixed setting at level 3 of the gain control of the phonocardiographic machine, and with

As the cuff pressure was lowered further, the ratio of sounds remained at about 90 per cent, until a point was reached at which the K/R ratio began to fall. In the course of a 10 mm. Hg drop the ratio fell to about 50 per cent. With a further drop of 10 or 20 mm. Hg, all sounds disappeared. These were consistent findings in all seven patients studied.

These data show, as is well appreciated, that significant fluctuations may occur in both systolic and diastolic blood pressure from beat to beat in patients with auricular fibrillation. However, despite these variations a definite and repeatable blood pressure level could be established. The present findings that the ratio of occurrence of Korotkoff sounds to electrocardiographic cycles approaches 50 per cent in a well demarcated cuff pressure zone shows the possibility of obtaining a satisfactory mean systolic and mean diastolic blood pressure

![Figure 1](http://circ.ahajournals.org/)

**FIG. 1.** The ratio of the number of sounds recorded at the brachial artery to the number of electrocardiographic cycles, at various levels of cuff pressure in four patients. Cuff pressure is given in the vertical axis; ratio of sounds to electrocardiographic cycles is given in the horizontal axis. The increasing incidence of sounds is depicted as cuff pressure falls from above systole to mean pressures. At a point below mean arterial pressures, the incidence falls again, reaching zero at 80 mm. Hg cuff pressure in one subject depicted and 60 mm. Hg in the other three shown. Discussed in text.

![Figure 2](http://circ.ahajournals.org/)

**FIG. 2.** Relation between previous cycle length and amplitude of the sound recorded at the brachial artery. All points given were obtained in a continuous run with cuff pressure maintained at 100 mm. Hg. The duration of the previous cycle is given as the R-R distance in the vertical axis. The amplitude of the recorded sound is given on the horizontal axis. Each point represents a single determination.
the cuff pressure held constant at 100 mm. Hg. 
As noted above, cycles of less that 0.4 second were not followed by an arterial sound. When the previous cycle ranged about 0.5 to 0.6 second, the amplitude for a given cuff pressure averaged 12 to 14 mm. With longer cycle lengths of approximately 0.8 second, the amplitude averaged 20 mm.

(4) Relationship between Durations of Sound and of the Previous Cycle. A general correlation was also shown between the durations of each cycle and of the succeeding sound (fig. 3). This relationship was most apparent at cuff compressions equal to about mean blood pressure values. At cuff pressure values approaching either the systolic or diastolic pressure levels, difficulties in the analysis were present, due in part to the fact that some of the pulses did not produce sounds.

(5) The Time of Onset of Korotkoff Sounds. In subjects with a regular cardiac rhythm, the time of onset of the brachial artery sound remains constant (±0.01 second) from beat to beat. However, in patients with cardiac irregularities, as in auricular fibrillation, the time of onset of the sound can be shown to be related inversely to the duration of the previous cycle (fig. 4). For example, at a cuff pressure of 100 mm. Hg, the onset of the Korotkoff sounds occurred at approximately 0.20 second when the preceding cycle was short (0.5 second); with longer preceding cycles this was reduced to as little as 0.13 second for long cycle length approaching 1 second. As noted above, and demonstrated in figure 4, there was an absence of brachial artery sound when the previous cycle lengths were less than 0.40 second.

Discussion

In auricular fibrillation, the incidence of sound production at the systolic and diastolic levels may be very irregular. This effect is enhanced by a tendency to an "auscultatory gap" in such patients, as suggested by the fall in incidence of sounds at about 30 mm. below the highest recorded systolic values (fig. 1). As a result, variations of 30 or 40 mm. Hg in the indirect estimation of the systolic blood pressure level, and somewhat smaller deviations of the diastolic, may be reported for a given patient by successive observers.

The present results suggest that a satisfactory measure of the mean systolic and diastolic pressures may be established by determining the ratio of the Korotkoff sounds to cardiac cycles at each of several cuff pressure levels. As the cuff pressure falls below the systolic pressure the ratio of the brachial artery sounds per minute increases over the course of about

![Figure 3](http://circ.ahajournals.org/)

**Fig. 3.** Relation between the duration of the previous cycle length and the duration of the sound registered at the brachial artery. Vertical axis gives the duration of the cycle previous to the occurrence of the sound. Duration of the sound is given in seconds on the horizontal axis. These data are from the same undisturbed run described in figure 2.

![Figure 4](http://circ.ahajournals.org/)

**Fig. 4.** The relation between the duration of the previous cycle to the time of onset of the brachial artery sound. The points given are for the same undisturbed run described in figure 2. Vertical axis gives the previous cycle length in seconds. Horizontal axis gives the time in seconds from onset of the QRS complex of the electrocardiogram until the onset of the sound at the brachial artery.
20 mm. Hg until it reaches a maximum rate. The number of cardiac cycles per minute may be obtained at the precordium as is done for determination of the pulse deficit, or by electrocardiographic monitoring. A mean systolic blood pressure level may be considered as that cuff pressure at which half of the apical beats are followed by brachial artery sounds, i.e., a deficit of 50 per cent.

As the cuff pressure falls further into the range of the diastolic pressure the incidence of the sounds is reduced progressively. When the incidence is reduced to about half that obtained at mean blood pressure, this value, obtained at a consistent level in each patient, may be considered to be the mean diastolic pressure.

The fact that no brachial artery sound was heard when the preceding cycle was less than 0.40 second is consistent with data that a short cycle may be inadequate to produce a pulse wave in the arterial system, probably as a result of inadequate filling of the ventricle, and the consequent weak or absent ejection phase. With cycle lengths longer than 0.5 second, the succeeding beats consistently produced a brachial sound, indicating that this duration in the patients studied was sufficient for pulse wave production.

In previous studies it has been demonstrated that the onset of the Korotkoff sounds signals the arrival of a pressure pulse equal to the compressing pressure in the sphygmomanometer cuff. The present studies suggest that the duration of the previous cycle can affect the time of arrival of the pulse wave. Thus, the greater the duration of the previous cycle, the shorter is the Q-K time of the succeeding beat. Such an effect might be due to a change in the rate of transmission of the pulse wave because of variations in the diastolic filling time and perhaps in stroke volume of the succeeding beat. This belief is supported by other evidence that the celerity of the transmission of the arterial pulse wave is related to the stroke volume. If this is proved to be the case, the time of arrival of the brachial artery sounds might provide an index of the relative stroke volume for successive beats.

The intensities of the brachial artery sounds probably are also related to the rate of rise of pressures in the aorta and in the brachial artery central to the cuff. The more powerful pressure pulse generated following longer cycle lengths thereby are seen as establishing the conditions for a louder burst of noise at the onset of the Korotkoff sound.

The relationship between the duration of the previous cycle and the intensities and durations of the brachial sounds also is consistent with the interpretation that an enhanced stroke output following a prolonged filling period is associated with a more forceful pulse wave causing a more adequate flow through the arteries under the cuff.

The foregoing studies illustrate that significant clinical information concerning some of the characteristics of the arterial pulse wave, the blood pressure and the blood flow through extremities may be obtained indirectly and with facility by utilizing the intermediate Korotkoff sounds.

**SUMMARY**

Simultaneous recording of the sounds at the brachial artery and of the electrocardiogram in seven patients with auricular fibrillation provided a basis for satisfactory estimation of the mean systolic and mean diastolic blood pressure levels. To obtain these values, the rate of occurrence of brachial sounds at a mean arterial pressure to apical beats is first determined. Higher or lower cuff pressures at which this rate is reduced to about 50 per cent are then used to determine the mean systolic and diastolic pressures respectively.

The time of the sounds and their intensities and durations are related to the duration of the preceding cardiac cycle and to a factor dependent on the blood pressure and the compression produced by the cuff.

For very short preceding cycles, no Korotkoff sound is heard or recorded. With longer preceding cycles, sounds are heard. The time from the Q wave of the electrocardiogram to the onset of the sound is shortened as the preceding cycle is more prolonged. This suggests that the transmission time of the pressure pulse wave in the arterial tree may be related to the stroke output. The intensity and dura-
tion of the sound, at least at mean arterial pressure levels, is also associated with the duration of the previous cycle, and presumably with the stroke output.

SUMMARIO IN INTERLINGUA

Le simultanee registration del sonos al arteria brachial e del electrocardiogrammas in septe patientes con fibrillation auricular esseva usate como base pro estimar le median nivellos del systolic e diastolic pression sanguinee. Pro obtenir iste valores nos primo determina le frequentia del sonos brachial a un median pression arterial. Postea le plus alte o plus basse pressiones de bracial pneumatic al quales ille frequentia es reducita a 50 pro cento es usate pro determinar le median pressiones systolic e diastolic, respectivelemente.

Le momento del sonos e lor intensitate e durationes es ponite in relation con le duration del precedente ciclo cardiac e con un factor que depende del pression sanguinee e del compression producite per le bracial pneumatic.

In le caso de brevissime cyclos precedente, nulle sono de Korotkoff es registrate o audite. In le caso de plus longe cyclos precedente, sonos de Korotkoff deveni audibile. Le intervallo de tempore ab le unda Q del electrocardiogramma usque al declaration del sono deveni plus breve in tanto que le cyclo precedente deveni plus longe. Isto pare indicar que le tempore del transmission del unda pulsatile de pression in le arboe arterial es possibilemente relationate al rendimento cardiac. Le intensitate e le duration del sono—al minus a nivellos median del pression arterial—es etiam associate con le duration del cyclo precedente e probablemente con le rendimento cardiac.

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