Dynamic Reactions Induced by Compression of an Artery

In 1941 a committee of the American Heart Association made some new "Recommendations for Human Blood Pressure Determinations by Sphygmomanometers." The report opened with a general statement from which we quote in part, "It should be clearly recognized that arterial pressures cannot be measured with precision by means of sphygmomanometers. . . . Despite this, clinical blood pressure determinations have proved very serviceable. . . . It is important, however, that any basic deficiency of sphygmomanometry be not increased by additional errors due to apparatus or technic."

The more recent scientific studies that led to the "Recommendations" were documented in that report. The dynamic reactions induced by compression of an artery were not discussed because it was felt that they usually neutralize one another. Nevertheless, it is important to realize that a number of basic problems remain to be explored by future investigators.

Historical

The use of a circular pneumatic cuff for compressing an artery is usually credited to Riva Rocci, but it was used concurrently by Hill and Barnard and described in the year following. Riva Rocci wrapped a flat rubber tube, 4.5 cm. wide and encased in a silk covering, around an arm and fastened it with a special clamp. Hill and Barnard employed a shorter rubber bag (20 cm. X 5 cm.) within a leather cuff and applied the inflatable bag over the inner aspect of the arm.

Clinicians promptly questioned the accuracy with which the pressure within the arm bag indicated the pressure on the outside of an artery. Earlier studies reviewed by Janeway seemed to satisfy investigators that losses of pressure through stretching the rubber bag or in overcoming tension of arterial walls were of little moment, but that the width of cuff in relation to arm girth was of considerable importance. The choice of the present wider cuff stems from von Recklinghausen's postulates on how pressure is transmitted through elastic structures of the arm under static conditions. The correctness of such deductions appeared to be validated by his formoscillographic method for evaluating systolic and diastolic pressures. The literature, however, abounds in reports indicating that a number of dynamic factors need to be considered before it is possible to define scientifically the proper width of a cuff under different circumstances. It is the purpose of this editorial to attempt to evaluate some of these dynamic factors from a modern perspective.

Production of Korotkoff Sounds

Since the first auscultatory sound is accepted almost universally as an index of systolic arterial pressure, our approach will be simplified by limiting the discussion to the dynamic factors that could invalidate accurate determination of systolic pressure by this criterion.

While the physical mechanisms concerned in the production of the first auscultatory sound deserve further study, it is reasonably certain that the first sound does not originate from commotion in the blood stream but that it arises from vibrations of the arterial wall at the distal end of the cuff. It is also highly probable that passage of a momentary jet of blood to this segment supplies the force which sets the arterial wall into vibration. Whether the jet causing the first sound is recordable as a small pressure wave in the artery peripheral to the cuff seems disputable. However, the observation that the first sound may be heard while cuff pressure still exceeds systolic pressure recorded directly from an artery of an opposite limb does not refute such a genesis of the first sound, as those who reported such occurrences recognized.

Augmentation of the Impinging Pressure Pulse

When a blood vessel is occluded, the kinetic energy ordinarily represented as flow is reconverted to potential energy of pressure. Studies
on models, animals and man have shown that such conversion of energy elevates systolic pressure but does not affect diastolic pressure. Consequently it has been held that the systolic end pressure or occlusion pressure, rather than the systolic lateral pressure, represents the force that drives blood through a compressed vessel. It has also been suggested that systolic pressure is further augmented by a water hammer effect or by summation of reflected waves. The augmentation of systolic pressure, thus produced at the upper margin of the cuff, has been variously estimated at 14 to 40 mm. Hg. After digesting the evidence presented by eminent authorities, the clinician may well be disturbed by the chance that his readings of systolic pressure may exceed their actual value by 30 to 40 mm. Hg.

This writer believes that there has been a general failure on the part of investigators to recognize that the contour of pressure pulses plays as important a role as amplitude in hemodynamic studies of this kind. Consequently, the applicability of information derived from models in which the form of the natural pressure pulse was not duplicated must be evaluated with greatest caution. Also the pertinence of experiments on femoral arteries in situ need to be reappraised, for it is well known that femoral pressure pulses differ materially from those in the brachial artery. As a step in this direction, Maltby and Wiggers used the left subclavian artery of the dog to study the effects of occlusion on central pressure pulses. The results revealed that clamping of this vessel does not affect the true systolic summit or basic form of the central pulse; it merely creates or intensifies an initial oscillation which is so brief that it could not possibly open for any distance a vessel collapsed by an external pressure. Furthermore, as Bazett and his associates pointed out, a pneumatic bag produces a conical closure of an artery and acts as an air cushion preventing sudden reflected waves of consequential amplitude. Unfortunately, one cannot be certain that such alterations also apply to the extension of the subclavian artery, i.e., the brachial artery. Acceptable records of lateral pressure pulses in the brachial artery of man have not, to our knowledge, been published. It may confidently be expected, however, that, through the combination of skillful operators and trustworthy pressure recorders, we may soon expect recordings from the brachial artery just above a cuff which will give definite information of contour as well as pressure changes during the entire process of inflating and deflating a cuff.

**Loss of Pressure Pulse Energy in Opening a Collapsed Vessel**

The foregoing considerations have stressed dynamic factors that may operate to give auscultatory readings of systolic pressure that are too high. Now those factors, that may act to make the readings too low, remain to be considered.

The systolic arterial pressure that we attempt to measure by the incidence of the first auscultatory sound exists only momentarily during each systole, actually for about .02 second. Hence the question, how long a distance of collapsed artery can be penetrated by such a temporary pressure. In 1921, Erlanger placed a femoral artery of a dog in a compression chamber and recorded the movements of several points along the artery by optical means. With his usual reserve, Erlanger drew the following conclusion:

"We have at present no information with regard to the length of artery that is occluded by the usual armlets under a compression that just counterbalances the arterial systolic pressure. If it is assumed that it amounts to only 4 cm., a minimal figure, and that the penetrability of the brachial artery of man to the pulse is the same as that of the femoral artery of the dog, it would follow that in man the systolic blood pressure readings, disregarding the error due to tissue resistance, are at least 8 mm. Hg too low."

Since the foregoing passage was written we have not advanced significantly in our understanding of the qualifying "ifs." On many points the experimental evidence is at variance; on others, the experiments missed the mark at which they were aimed.

We have made little progress in assessing the length of artery compressed by armlets in...
common use. By employment of angiographic technics, Anschütz & Burkert have recently found that radio-opaque material injected into a femoral artery, occluded by a cuff pressure 40 mm. Hg higher than brachial systolic, penetrated 6 cm. under the thigh cuff. But the test loses its significance, because of the erroneous assumption that femoral and brachial systolic pressures are identical. However, such angiographic studies during, as well as before, decompression might give valuable information as to the length of artery actually closed by cuffs of different sizes.

Since any impinging pressure pulse is damped in the temporarily opened artery, it loses some of its force and its transit is slowed to less than 1 M./sec. according to Frank and Wezler. Consequently, it may be assumed that the brachial pressure pulse with its more sustained systolic summit might penetrate a longer segment of collapsed artery than a peaked femoral pulse with an equivalent systolic pressure. Recent experiments on models would seem to support such an idea. However, this would be true only provided passage of the pulse wave requires that the systolic pressure in an arterial segment exceeds the compression pressure during the whole interval of transit. Experiments of Bazett, Laplace and Scott indicated that this need not be the case; owing to the low volume elasticity of the compressed segment, blood entering a proximal segment during early systole may be pushed forward during late systole, as a “bolus” after intra-arterial has fallen below extra-arterial pressure.

According to Anschütz, the amount of decrement that a pressure pulse undergoes depends not only on the length of segment penetrated but also on the anacrotic gradient of the pressure pulse, or expressed physically, on its high frequency components. This may account for the clinical experience, occasionally reported, that a radial pulsation is detectable before a sound. Drube and Anschütz have recently presented a record which shows that, of the waves which pass the cuff after an injection of norepinephrine, only those that display a sharp ascent are accompanied by a sound.

The pressure pulse also loses energy by transmitting pressure to the bag and sphygmomanometer system. This is shown by the fact that cuff pressure is not constant throughout the heart cycles as is erroneously inferred from reading pressures on a damped mercury manometer. When cuff pressures are recorded by adequate manometer systems, they display a rise during early systole and a fall during late systole and throughout diastole. In fact, the pressures so transmitted can be felt so well that experienced observers are able to estimate systolic and diastolic pressures by sensations alone. The component of arterial pressure thus transferred to the tissues and bag cannot be used to push the pulse wave through the artery; cuff pressure must, therefore, decline considerably below systolic arterial pressures before a pulse wave reaches the distal end of the compressed vessel and produces a sound.

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REFERENCES
EDITORIAL


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_Circ Res._ 1956;4:4-7
doi: 10.1161/01.RES.4.1.4

_Circulation Research_ is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7330. Online ISSN: 1524-4571

The online version of this article, along with updated information and services, is located on the World Wide Web at:

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