In auscultatory Riva Rocci Korotkoff (RRK) blood pressure determinations, the systolic blood pressure is by definition read at the point at which the first of at least two connective beats is heard.\(^1\,^2\) On comparing direct and indirect blood pressure determinations in a measurement comparison study, we observed that the instant of Korotkoff phase 1 (K\(1\)) coincided with a peak in systolic intra-arterial pressure (IAP) more often than could be explained by chance alone. We then realized that this finding is inherent to the occluding cuff technique with its gradually decreasing cuff pressure. Like a valley that is shielded from the sun by surrounding mountains, a beat with a systolic pressure lower than the prevailing average probably cannot cause the first Korotkoff sounds if it is preceded by a beat with a higher systolic pressure. Beats with a relatively high systolic pressure are much more likely to be the first beat at which the systolic pressure is higher than the concurrent cuff pressure, thereby causing the first Korotkoff sounds. Therefore, a systematic elevation of the systolic RRK readings might occur, especially in persons with a high blood pressure variability. Furthermore, such a phenomenon could affect results of studies in which indirect and direct blood pressure measurements are being compared.

To evaluate the effect of blood pressure variability on Riva Rocci Korotkoff blood pressure determinations, we studied the intra-arterial pressure during Riva Rocci Korotkoff determinations in 25 patients. In 50 measurements with a cuff deflation rate of 2.5 mm Hg/sec, the systolic intra-arterial pressure at Korotkoff phase 1 was 2.1 (95% confidence interval 1.2-3.0) mm Hg higher than the average systolic intra-arterial pressure in the 20 seconds surrounding this moment (\(p<0.01\)). This elevation was shown to increase with increasing blood pressure variability, as expressed by the standard deviation of the systolic blood pressure. The elevation caused by the proposed mechanism was amplified when a slow cuff deflation rate of 1.5 mm Hg/sec was used. No significant difference was noted in the diastolic intra-arterial pressure at Korotkoff phase 5, when a normal deflation rate of 2.5 mm Hg/sec was used. A slow cuff deflation rate caused a small elevation in diastolic pressure at the moment of Korotkoff phase 5. We conclude that even normally occurring blood pressure variability might lead to a consistent elevation of systolic Riva Rocci blood pressure measurements. This effect is reinforced by an increasing blood pressure variability and by a slower cuff deflation rate. (Hypertension 1992;19:606-609)

**KEY WORDS** • blood pressure determination • blood pressure • essential hypertension

To quantitate the effect of blood pressure variability on RRK blood pressure determinations, we compared the IAP at the moment of K\(1\) and Korotkoff phase 5 (K\(5\)) with the IAP during the 20 seconds surrounding the appearance and disappearance of the Korotkoff sounds.

**Methods**

**Patients**

Direct and indirect blood pressures were measured simultaneously in 25 elderly patients participating in a study of pseudohypertension in the elderly. Sixteen patients underwent coronary angiography because of angina pectoris (mean age, 65 years; M: F, 14:2; RRK blood pressure, systolic mean 151 [range, 123-201], diastolic mean 78 [range, 57-102] mm Hg); nine had their intra-arterial brachial pressures measured because of therapy-resistant hypertension (mean age, 66 [range, 52-79] years; M: F, 6:3; RRK blood pressure, systolic mean 186 [range, 133-240], diastolic mean 88 [range, 72-119] mm Hg).

The study was approved by the hospital ethics committee, and all participants gave informed consent.

**Riva Rocci Korotkoff Measurements**

Two supine RRK measurements were performed in each patient, using an electronically controlled normal deflation rate of 2.5 mm Hg/sec, a standard mercury manometer, and a 14 x 38 cm cuff.\(^3\) As part of the protocol, and to elucidate the mechanism at work, two additional RRK measurements with a slow deflation rate of 1.5 mm Hg/sec were performed in each patient. The instant of appearance and disappearance of the Korotkoff sounds (K\(1\) and K\(5\)) were marked electrically. The measurements were performed by either one
of two experienced observers, who had both recently passed audiographic testing.

**Intra-arterial Measurements**

The IAP was obtained either in the aortic arch in the patients undergoing cardiac catheterization or in the contralateral brachial artery in the patients with therapy-resistant hypertension. Fluid-filled catheter manometer systems were used with natural frequencies ranging from 10 to 34, and damping coefficients ranging from 0.22 to 0.64. Intra-arterial as well as cuff pressures were recorded on a HP 3964 A tape recorder (Hewlett Packard, Palo Alto, Calif.), and A/D converted on a Compaq 386 personal computer (Compaq Computer Corporation, Houston, Tex.). Due to peripheral reflections the absolute systolic IAP might differ between the two measurement sites. However, since we do not use the absolute IAP level, but rather its variability, we believed the use of two different measurement sites would not affect the results. Accordingly, the analysis was performed on the pooled results.

**Analysis**

After digitization of the signals, the beats at the instants of K1 and K 5 were compared with the average IAP during the 20 seconds around these beats. The standard deviations of the systolic and diastolic IAP during this 20-second period were used as measures of blood pressure variability. Results are expressed as mean and 95% confidence interval (CI) of the average of the two RRK determinations with the same deflation rate in each patient. The difference between the systolic IAP at K1 and the 20-second average systolic IAP, the elevation of the systolic IAP at K 1, was tested with a two-sided paired Student’s t test. Linear regression analysis was used to correlate the standard deviation and the elevation of the systolic IAP at K1.

**Results**

**Simultaneous Riva Rocci Korotkoff and Intra-arterial Blood Pressure Determinations**

In Figure 1A the systolic IAP during the 10 seconds before and the 10 seconds after the first Korotkoff sounds in 50 normal RRK measurements with both deflation rates is shown. Using a normal deflation rate of 2.5 mm Hg/sec, the systolic IAP at K 1 was 2.1 mm Hg higher than the average systolic IAP (n=25; 95% CI, 1.2–3.0 mm Hg; p<0.001). For a deflation rate of 1.5 mm Hg/sec the corresponding figures were 2.7 mm Hg (n=25; 95% CI, 1.7–3.6 mm Hg; p<0.001). The “interference pattern” shown in Figure 1A was amplified when the slow deflation rate was used, as can be seen from the increased difference between the IAP at t=0 and t = –1.5 seconds (p<0.05).

The difference between the systolic IAP at K1 and the average systolic IAP correlated with the standard deviation of the systolic IAP (3.56; 95% CI, 3.0–4.1 mm Hg) during the 20-second period (r=0.47, p<0.05; Figure 2). After exclusion of one outlier, in which the large standard deviation was not caused by phasic blood pressure variability, but by a continuously decreasing blood pressure during the measurement, the correlation coefficient becomes 0.71 (p<0.01).

The diastolic IAP was not elevated at K 5 (0.3 mm Hg; 95% CI, –0.1–0.8 mm Hg). Using a deflation rate of 1.5 mm Hg/sec, the diastolic IAP at K 5 was increased (1.4 mm Hg; 95% CI, 0.5–2.3 mm Hg; p<0.001). The standard deviation of the diastolic IAP (1.93 mm Hg; 95% CI, 1.7–2.2) was smaller than the standard deviation of the systolic IAP (p<0.001).

**Discussion**

The RRK blood pressure will be determined at a higher level when the IAP at the moment of K1 is higher than the average systolic IAP. Our observations of the IAP during RRK measurements show that the systolic IAP at K1 was higher than the average systolic IAP indeed. The interference pattern around K 1, visible in Figure 1, suggests that this phenomenon is caused by the fact that K 1 is frequently detected during a period of rising IAP.

As might be expected from the analogy with the low standing sun in the mountains (the average altitude at which one can enjoy the sun increases when the moun-
tains are higher, the distance between the mountain ridges is smaller, or when the sun stands lower), the elevation of the systolic IAP at K 1 was larger when the variability of the systolic IAP was increased. As expected, the choice of the intra-arterial measurement site did not affect this relation (Figure 2). Furthermore, the interference pattern was amplified when the cuff was deflated at a slower rate (Figure 1). Since the first Korotkoff sounds may be detected at any beat, which is not in the "shadow" of preceding beats, the level of overestimation may vary from one RRK reading to another. Therefore, the level of the elevation at K 1 may vary between RRK readings, even if the blood pressure variability is identical.

Contrary to what has been suggested,
the described phenomenon had no effect on the determination of the diastolic pressure if a normal deflation rate was used. This is most likely caused by the fact that variations in diastolic blood pressure are much smaller than variations in systolic blood pressure. Even when a slow deflation rate was used, we found no decrease of the diastolic IAP at K 5, but rather an increase, for which we have no ready explanation.

Although the average elevation was only 2.1 mm Hg, this phenomenon has important consequences. Short-term variations in blood pressure will not only result in varying blood pressure determinations but in even consistently higher systolic RRK readings. However, it is not only the systematic nature of this phenomenon that causes concern, but also the range of blood pressure elevation at K 1. In our population the maximal elevation of the systolic IAP at K 1 in a single RRK reading was 12.3 mm Hg. Therefore, clinically important elevations do occur in individual blood pressure determinations but in even

Therefore, the phenomenon might be expected to occur at all ages. Furthermore, the variability, and therefore the elevation in RRK readings, may change from one moment to another, thus causing different amounts of elevation at different occasions. Time-dependent differences can for example be caused by differences in respiration pattern,6,9 body position,10 and blood pressure.6,7 Only when we hear an auscultatory gap of the first type, as recently described by Blank and others,4,11 can we be certain that the above described mechanism does play a role. Blank et al4 raised the question of how to determine the RRK systolic blood pressure when an auscultatory gap of this type is present. Our results show that determination of the systolic pressure at the first Korotkoff sound certainly leads to an overestimation of the systolic pressure. However, determination at the reappearance of the Korotkoff sounds might lead to an underestimation of the systolic pressure. A useful solution, which would have to be investigated, might be to use the pressure at the last K 1 sound before the gap.

Of more specialized interest is the effect of the above described mechanism on studies in which indirectly determined blood pressures are compared with intra-arterial values. We have shown that the systolic IAP at the moment of K 1 is higher than the average systolic IAP during the surrounding period. Therefore, the generally observed underestimation of the systolic IAP by RRK readings will decrease when the average systolic IAP over a certain period is used rather than a single value of the IAP at K 1. Since the standard deviation of the presently described phenomenon is much smaller than the standard deviation of RRK–IAP differences, this phenomenon explains only to some extent the variation in RRK versus IAP comparisons. In conclusion, even normal blood pressure variability might lead to a consistent elevation of systolic RRK readings. This effect is reinforced by an increasing blood pressure variability and will lead to clinically important elevations of the systolic blood pressure in patients with a higher than normal blood pressure variability and to a source of error in comparative blood pressure studies.

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**In General:**

Quinapril is not expected to affect labor and delivery in humans. There are no adequate and well-controlled studies in pregnant women. The incidence of adverse events in women taking Accupril for cardiovascular disease was 4.9%. Severe depression or suicidal ideation have been reported with Accupril use, although no specific cause has been established. In a case-controlled study of 3,043 elderly hypertensive patients, no association with Accupril therapy was noted.

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Quinapril hydrochloride was not a mutagen in studies in bacteria, yeasts, or mammalian cells.

**In General:**

Quinapril hydrochloride was not a carcinogen in laboratory animals. Quinapril was not associated with an increase in tumors in rats administered doses up to 10 times the maximum recommended human dose, when based on body surface area.

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