How Should Diastolic Blood Pressure Be Defined During Pregnancy?

Seymour G. Blank, Geri Helseth, Thomas G. Pickering, James E. West, Phyllis August

Abstract Controversy exists concerning the most accurate method for defining diastolic blood pressure in pregnancy. Both disappearance (phase V) and muffling (phase IV) of Korotkoff sounds have been advocated. We previously reported an objective noninvasive method for measuring blood pressure, called K2 analysis, which in nonpregnant subjects was not different from intra-arterial diastolic blood pressure and was more accurate than the auscultatory technique. For determination of the relation of diastolic blood pressure (using K2) in pregnancy with muffling and disappearance of Korotkoff sounds, 58 women (42 hypertensive, 16 normotensive) underwent 556 blood pressure evaluations in the supine position at various stages of pregnancy. K2 analysis was compared with simultaneous auscultation by two observers, A1 (n=461 observations; 364 hypertensive, 97 normotensive) and A2 (n=415; 316 hypertensive, 99 normotensive). Overall, muffling was detected by observer A1 52.9% (244/461) and by observer A2 44.3% (184/415) of the time. When evaluated by clinical classification, muffling was found by both observers to be present less often in the hypertensive group (A1: 47.5%; A2: 37.3%) compared with the normotensive group (A1: 73.2%; A2: 66.7%) (P<.00001). When both observers were present (n=348), they agreed that muffling was present only 112 times. Disappearance of sound was detected by both observers 98.3% (A1: 453/461; A2: 408/415) of the time. Muffling overestimated K2 diastolic pressure by 7 to 10 mm Hg, whereas there was no statistically significant difference between disappearance and K2 diastolic pressure for hypertensive subjects and a 2.5-mm Hg underestimation of K2 diastolic pressure for normotensive subjects. Both observers were able to obtain a greater percentage of readings within 5, 10, and 20 mm Hg of K2 diastolic pressure using disappearance rather than muffling. However, there were individual blood pressure determinations during which sounds were heard significantly below (or above) K2 diastolic blood pressure (7.9% of A1's and 18.9% of A2's disappearance determinations were greater than 10 mm Hg away from K2 diastolic pressure), including measurements in which muffling was closer to K2 diastolic pressure. In the 112 determinations in which muffling and disappearance were detected by both observers, interobserver variability of muffling was approximately equal to disappearance. For both observers, the differences between muffling and disappearance were large (A1: muffling 11.3 mm Hg above disappearance; A2: muffling 9.7 mm Hg above disappearance) and were not significantly affected by hypertensive status. We conclude that on average, the disappearance of sound (phase V) is a more accurate, reliable, and less variable measurement of diastolic blood pressure in pregnancy than muffling (phase IV). (Hypertension. 1994:24:234-240.)

Key Words • blood pressure • blood pressure determination • pregnancy • auscultation • wideband external pulse recording • K2 analysis

Hypertension during pregnancy is associated with considerable maternal and fetal morbidity and mortality.1 The timely recognition of an elevated diastolic blood pressure (DBP), particularly during late pregnancy, is essential to the appropriate care of pregnant women.2 Despite this, there is no universally accepted consensus on a standard for its measurement. The auscultatory technique, developed by N.S. Korotkoff in 1905,3 is the most widely accepted noninvasive method for blood pressure (BP) measurement, and most of the data about arterial pressure in pregnancy have been obtained with its use. The controversy regarding BP measurement in pregnancy has centered around the use of phase V "disappearance" (DP5) as opposed to phase IV "muffling" (DP4) of the Korotkoff sound as the best indicator of true DBP.

Supporters of phase IV muffling2,4-6 claim that it is a more reliable criterion than disappearance for several reasons. First, Korotkoff sounds in pregnant women are often audible to cuff pressures of 0 mm Hg; second, the detection of a change in quality of sound depends less on the sensitivity of the observer's hearing and position of the stethoscope; and third, there is a stronger theoretical connection of muffling to intra-arterial DBP. Some authors have even stated that muffling is more accurate than disappearance.2,5-7

Supporters of phase V disappearance argue that phase IV is not always present, that the detection of muffling has large intraobserver variability, that the disappearance of sound is a more accurate reflection of intra-arterial DBP, and that the lack of disappearance of sound in pregnancy is overstated.8,9

The validation of auscultatory BP determinations in pregnancy has traditionally required invasive intra-arterial measurements, which for obvious reasons are not clinically practical. We have developed an objective noninvasive method of BP measurement that uses analysis of the brachial wideband external pulse (WEP) recorded during cuff deflation.10-12 WEP recording is based on the ability of a pressure sensor to record inaudible frequencies (down to 0.1 Hz) during cuff
Defining DBP in Pregnancy

A tracing shows representation of cuff pressure \( P(c) \) being reduced from above systolic pressure (SP, point A) to below diastolic pressure (DP, point B). Shaded areas above cuff pressure represent positive pressure gradients (arterial pressure - cuff pressure) and shaded areas below \( P(c) \) represent negative pressure gradients. Tracings show changes in the wideband external pulse (WEP) as \( P(c) \) is reduced from above to below SP. With \( P(c) \) greater than SP, only the K1 component of WEP is present. At SP, K2 appears superimposed on the K1 component. With \( P(c) \) below SP, K3 appears. Tracings show changes in WEP as \( P(c) \) is reduced from above to below DP. The K2 notch disappears (leaving K3 as the only WEP component present) as \( P(c) \) is reduced below DP.

deflation. Three distinct components of the WEP signal can be detected (called K1, K2, and K3), one of which, K2, appears and disappears at systolic blood pressure (SBP) and DBP, respectively. It should be noted that K1, K2, and K3 are not related to the five phases of the Korotkoff sound. The appearance and disappearance of K2 are based on the visual recognition of a pattern as opposed to the audible recognition of sound and thus are not affected by the vagaries of auscultation. We have shown previously that differences between indirect and intra-arterial measurements in nonpregnant subjects were significantly less for K2 than for the auscultatory method. Thus, the K2 analysis technique may represent an alternative to invasive intra-arterial measurement in assessing the accuracy of indirect cuff measurements in pregnancy.

The main purpose of this study was to investigate whether DBP, as measured by K2 analysis, correlated more closely with muffling or disappearance of the Korotkoff sound in pregnant women. An additional purpose was to determine the reliability and variability of both muffling and disappearance.

Methods

Subjects

The results reported are derived from 556 BP determinations on 58 women throughout their pregnancies. Forty-two women were classified as having chronic essential hypertension and 16 were normotensive. Their mean age was 32.5±5.4 years (mean±SD), with a range of 21 to 42 years. The ages of the normotensive and hypertensive subjects were similar. Sixty-one BP measurements were made on 16 subjects during the first trimester, 235 determinations were made on 46 subjects during the second, and 260 measurements were made on 46 subjects during the third. Three or four BP measurements were made on each subject at each measurement session. All subjects gave informed consent to the study protocol.

Techniques

The WEP was recorded with a specially designed (AT&T Bell Laboratories) foil electret sensor (FES) that is similar in principle to conventional electret microphones used for airborne sound reception. When coupled to a high-impedance amplifier, the FES has a flat frequency response from below 0.1 Hz to above 2000 Hz. Detailed characteristics of this sensor have been described previously.

Recordings were obtained with the subject in the supine position. An FES was positioned over the brachial artery approximately 1 inch above the antecubital space. A BP cuff with a bladder of recommended width\(^{13}\) that encircled the arm was placed such that the distal end of the cuff coincided with the distal end of the FES. WEPs were recorded as cuff pressure was reduced from above SBP to below DBP. The signal from the FES was coupled with a high-impedance (10 M\(\Omega\) \(\Omega\)) electrometer amplifier (Keithley Instruments) and then into a direct-current DCV-20 amplifier of a VR6 physiologic recording system (Electronics for Medicine).

A detailed description of how the WEP pattern changes as cuff pressure is reduced from above SBP to below DBP (Figure, a) has been described previously.\(^{10}\) and typical representations are shown in the Figure (b and c). The inaudible low-frequency signal recorded with cuff pressure above SBP is called the K1 pattern. K2 is a high-frequency signal that...
appears at SBP (Figure, b) and disappears at DBP (Figure, c). K3 is a large-amplitude, low-frequency signal that appears at cuff pressures between SBP and DBP (Figure, b) and is the only WEP component visually present with cuff pressures below DBP (Figure, c). The K2 algorithm states that SBP is the cuff pressure when K2 initially appears in the WEP signal and that DBP is the cuff pressure at the last visual representation of K2 as cuff pressure is deflated below DBP.

Simultaneous auscultation was performed by one or two trained observers (A1 and A2) listening through a dual stethoscope. Observer A1 was either a physician or a research nurse, and observer A2 was always S.G.B. Observer A1 (physician: 334 determinations, 48 subjects; research nurse: 127 determinations, 18 subjects) was present for 461 of the 556 BP determinations (364 hypertensive, 97 normotensive, 56 subjects) and observer A2 was present for 413 (316 hypertensive, 99 normotensive, 45 subjects). It should be noted that the agreement between observers was similar regardless of observer A1 being the physician or nurse. Two observers were present for 348 (280 hypertensive, 68 normotensive, 43 subjects) BP determinations.

The stethoscope head was placed over the previously palpated brachial artery just distal to the BP cuff and the FES and was held firmly in position without excessive pressure by an elastic strap, ensuring that the surface of the stethoscope was maintained flush against the skin. The elastic strap minimized extraneous noise caused by human touch. The stethoscope was modified to enable Korotkoff sounds to be electronically recorded. This was accomplished by adding a Y connector and coupling the additional air-filled pathway to a pulse transducer (Cambridge Electronics). The Cambridge pulse transducer was coupled to a VR6 2207 phonocardiographic amplifier. The electrocardiogram was also recorded. The cuff was rapidly inflated to a pressure above SBP. That the cuff pressure was above SBP could be visually confirmed by viewing the WEP and noting the characteristic K1 pattern, which is seen with cuff pressure above SBP. The pressure in the cuff was manually controlled with a rotary pressure regulator handle of an E-10 cuff pressure inflator/regulator (Hokanson) and was read by a pressure transducer (model T4812 AD-R, Gould-Statham) connected to a PDV-20 pressure amplifier in the VR6 and displayed by a mercury column. With minimal training, observers could deflate the cuff pressure smoothly at a rate of 2 to 4 mm Hg/s. Observer A1 read the mercury column at onset, muffling, and disappearance of sound, as per normal auscultatory BP determinations. Auscultatory observer A2 used a switch to mark, blindly to A1, the onset, muffling, and disappearance of sound. The American Heart Association recommendation of "a distinct, abrupt, muffling of sound" was used as the indication for the fourth phase of the Korotkoff sound. Each channel of the VR6 recorder was sampled at 500 Hz by a 12-bit analog-to-digital convertor for storage into an IBM PC/AT computer using the CODAS (Dataq Inc) data-acquisition software.

In the present study, for determination of whether DBP (as defined by K2) in pregnancy related better with muffling (DP4) or disappearance (DP5), K2 analysis was compared with simultaneous auscultation at various stages of pregnancy. DP4 and DP5 were compared with respect to reliability (ie, how often were muffling and disappearance of sound detectable?), accuracy (ie, how close were DP4 and DP5 to K2 DBP?), interobserver variability (ie, how well did two simultaneous observers’ estimates of muffling and disappearance agree with each other?), and intraobserver differences (ie, how different was each observer’s determination of DP4 from DP5?). In addition, the reliability, accuracy, and intraobserver differences of DP4 and DP5 were examined with respect to clinical status (ie, hypertensive versus normotensive).

Note that in the present study a DP5 determination below 35 mm Hg was considered a nonphysiological value and was treated as if sound were heard to 0 mm Hg.

**Table 1. Detection of Muffling and Disappearance of Korotkoff Sounds: All Observations**

<table>
<thead>
<tr>
<th>Observer</th>
<th>n</th>
<th>Subjects</th>
<th>Muffling</th>
<th>Disappearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>461</td>
<td>56</td>
<td>244 (52.9%)</td>
<td>453 (98.3%)</td>
</tr>
<tr>
<td>A2</td>
<td>415</td>
<td>45</td>
<td>184 (44.3%)</td>
<td>408 (98.3%)</td>
</tr>
</tbody>
</table>

**Data Analysis**

Auscultated and K2 values for SBP, DP4, and DP5 were compared using Student's t test. For the clinical subgroups, the differences between both muffling and disappearance and K2 DBP were compared by independent t test. The discrepancies of unreliable DP4 measurements between normotensive and hypertensive subjects were obtained using a χ² analysis with contingency correction.

**Results**

**Reliability: Detection of Muffling and Disappearance**

Phase IV muffling was detected in 244 of the 461 BP determinations (52.9%) made by observer A1 (Table 1) and in 184 of the 415 BP determinations (44.3%) made by observer A2. Observer A1 heard Korotkoff sounds to 0 mm Hg on two separate occasions in 1 of 56 subjects (6 BP determinations). On two additional measurements on a different subject, observer A1 could not reliably determine the disappearance of sound. Observer A2 heard Korotkoff sounds to 0 mm Hg in 2 of 45 subjects for a total of 7 BP determinations. Thus, DP5 could be successfully determined in 98.3% of occasions by both observers (A1: 453 of 461; A2: 408 of 415).

When both observers were present (n=348) (Table 2), A1 could detect the presence of DP4 164 of 348 times (47.1%), and A2 could detect the presence of DP4 158 times (45.4%). Of the 164 times A1 heard muffling, A2 agreed with the presence of muffling 112 times (68.3%). Of the 158 times A2 heard muffling with A1 present, A1 agreed with the presence of muffling 112 times (70.9%). Looking at DP5 in a similar manner, A2 could detect the disappearance of sound 348 times (100%), and A1 could detect the disappearance of sound in 346 of 348 (99.4%) determinations. On the two occasions when A1 could not reliably determine DP5, A2 measured BP of 113/103 and 109/103 mm Hg, respectively, while K2 measured BPs of 119/74 and 121/73 mm Hg, respectively. Thus, the premature disappearance of Korotkoff sounds (generating a physiologically implausible pulse pressure) rather than sound being heard to 0 mm Hg led to difficulty in the determination of DP5 by A1. Note that with both observers present, sound was never heard below 35 mm Hg by either observer.

When evaluated by clinical classification, DP4 was found by both observers to be undetectable more often in the hypertensive group (A1: 191 of 364, 52.5%; A2: 198 of 316, 62.7%) than in the normotensive group (A1: 26 of 97, 26.8%; A2: 33 of 99, 33.3%) (P<.00001). With
Table 3. Differences Between Auscultatory and K2 Determinations of Blood Pressure

<table>
<thead>
<tr>
<th>A. Muffling (DP4)</th>
<th>DP4−K2DP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A1 (N=244)</td>
</tr>
<tr>
<td>Mean (SD), mm Hg</td>
<td>9.2 (7.0)*</td>
</tr>
<tr>
<td>Within 5 mm Hg, % (n)</td>
<td>35.7 (87)</td>
</tr>
<tr>
<td>Within 10 mm Hg, % (n)</td>
<td>65.6 (160)</td>
</tr>
<tr>
<td>Within 20 mm Hg, % (n)</td>
<td>92.6 (222)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B. Disappearance (DP5)</th>
<th>DP5−K2DP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A1 (N=453)</td>
</tr>
<tr>
<td>Mean (SD), mm Hg</td>
<td>−0.5 (6.3)</td>
</tr>
<tr>
<td>Within 5 mm Hg, % (n)</td>
<td>72.2 (327)</td>
</tr>
<tr>
<td>Within 10 mm Hg, % (n)</td>
<td>92.1 (417)</td>
</tr>
<tr>
<td>Within 20 mm Hg, % (n)</td>
<td>99.1 (449)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C. Systolic Pressure (SP)</th>
<th>SP−K2SP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A1 (N=461)</td>
</tr>
<tr>
<td>Mean (SD), mm Hg</td>
<td>−2.7 (4.0)*</td>
</tr>
<tr>
<td>Within 5 mm Hg, % (n)</td>
<td>77.7 (358)</td>
</tr>
<tr>
<td>Within 10 mm Hg, % (n)</td>
<td>95.2 (439)</td>
</tr>
<tr>
<td>Within 20 mm Hg, % (n)</td>
<td>100 (461)</td>
</tr>
</tbody>
</table>

DP4 indicates auscultatory diastolic pressure using muffling; K2DP, diastolic pressure by K2 analysis; DP5, auscultatory diastolic pressure using disappearance; SP, auscultatory systolic pressure; and K2SP, systolic pressure by K2 analysis.

Table 4. Interobserver Variability of Muffling and Disappearance

<table>
<thead>
<tr>
<th>Interobserver Difference</th>
<th>A1DP4−A2DP4</th>
<th>A1DP5−A2DP5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (SD), mm Hg</td>
<td>1.0 (6.6)</td>
<td>−1.2 (4.1)*</td>
</tr>
<tr>
<td>Within 5 mm Hg, % (n)</td>
<td>79.5 (89)</td>
<td>83.0 (93)</td>
</tr>
<tr>
<td>Within 10 mm Hg, % (n)</td>
<td>94.6 (106)</td>
<td>92.9 (104)</td>
</tr>
<tr>
<td>Within 20 mm Hg, % (n)</td>
<td>96.4 (108)</td>
<td>100 (112)</td>
</tr>
</tbody>
</table>

A1DP4 indicates observer A1 diastolic pressure using muffling; A2DP4, observer A2 diastolic pressure using muffling; A1DP5, observer A1 diastolic pressure using disappearance; and A2DP5, observer A2 diastolic pressure using disappearance.

Table 3 also shows the relations of the auscultatory and K2 determinations of SBP. When evaluated by clinical classification, hypertensive DP5 did not differ from K2 DBP, whereas normotensive DP5 of both observers averaged 2.5 mm Hg below K2. The normotensive versus hypertensive DP5 difference from K2 DBP was statistically significant (A1: P<.0005; A2: P<.005) but numerically small. Normotensive DP4 averaged 7.6 and 7.2 mm Hg above K2 DBP for observer A1 and A2, respectively, whereas hypertensive DP4 for observer A1 and A2 averaged 10.0 and 8.7 mm Hg above K2, respectively. Hypertensive status did not in any consistent fashion affect the likelihood of DP4 or DP5 being within 5, 10, or 20 mm Hg of K2 DBP.

Interobserver Variability

Interobserver variability was evaluated in the 112 BP determinations (27 subjects) in which muffling and disappearance were both detected by each observer (Table 4). If there was agreement between observers on muffling being present, interobserver variability in determining when muffling and disappearance occurred was minimal. A2 measured a slightly lower DP4 (1.0 mm Hg) and a slightly higher (1.2 mm Hg) DP5 than observer A1. Similar muffling and disappearance results were obtained by both observers when evaluating the percentage of A1 readings within 5, 10, and 20 mm Hg of A2. A1 and A2 measured phase IV muffling within 5 mm Hg of each other 79.5% of the time. A1 and A2 measured disappearance within 5 mm Hg of each other 83.0% of the time. They recognized phase IV muffling within 10 mm Hg of each other 94.6% of the time and phase V disappearance 92.9% of the time. Within 20 mm Hg, these numbers increased to 96.4% and 100% for muffling and disappearance, respectively.

Intraobserver Difference Between Muffling and Disappearance

Intraobserver differences between muffling and disappearance were evaluated for those BP determinations in which both muffling and disappearance were recognized by each observer (Table 5). The muffling-disappearance differences perceived by each observer were large and not significantly related to the duration of pregnancy or the subject’s hypertensive status. Observer A1, in 238 determinations, recognized DP4 to occur, on average, 11.3 mm Hg above DP5. A2 recorded DP4 9.7 mm Hg above DP5. Observer A1 identified only 54 of 238 determinations (22.7%) (A2: 60 of 180, 33.3%) in
which muffling and disappearance were within 5 mm Hg, 148 of 238 determinations (62.2%) (A2: 115 of 180, 63.9%) within 10 mm Hg, and 213 of 238 determinations (89.5%) (A2: 164 of 180, 91.1%) within 20 mm Hg. Thus, whether one took muffling or disappearance as the indicator for DBP could result in rather substantial differences.

**Discussion**

The dilemma of whether to use phase IV muffling or phase V disappearance of the Korotkoff sound as the most appropriate measure for DBP in pregnancy is long-standing. This controversy has significant clinical implications because diagnosis and management of preeclampsia, a life-threatening complication of pregnancy, rest on the ability to accurately monitor BP. We have tried to resolve this dilemma by using K2 analysis, an objective noninvasive method of BP measurement that has been shown to correlate well with intra-arterial measurement of DBP and is more accurate than the auscultatory technique in nonpregnant subjects.¹ We recognize the limitation of using a standard that has been verified in only nonpregnant subjects; however, we submit that K2 analysis is a suitable standard for the following reasons: First, previous evidence supports the idea that the appearance and disappearance of K2 depend primarily on pressure gradient (ie, intra-arterial minus cuff pressure) reversals and are less sensitive to hyperkinetic (or hypokinetic) blood flow states¹⁰,¹², seventeen, second, the results reported here are consistent with almost all previous intra-arterial pregnancy studies which show that disappearance rather than muffling of Korotkoff sounds more accurately reflects true DBP in pregnancy.

In the present study we found that muffling overestimated K2 DBP by 7 to 10 mm Hg (depending on observer and/or hypertensive status), whereas on average for both observers, there was no difference between the disappearance of sound and K2 DBP for hypertensive subjects and a 2.5 mm Hg underestimation of DBP for normotensive subjects.

An additional goal of this study was to determine the reliability and variability of both muffling and disappearance of the Korotkoff sound in pregnancy and thus determine which measurement is more useful. We found that muffling was detected less frequently than the disappearance of sound and that the inability to detect muffling was greater in hypertensive than normotensive individuals. In contrast, both observers were able to detect the disappearance of sound 98.3% of the time. With respect to variability, when both observers agreed that phase IV was present, the agreement on phase IV and phase V between the two observers was similar.

Historically, the question of whether to use phase IV muffling or phase V disappearance of the Korotkoff sound as the most appropriate measure for DBP has not been restricted to pregnancy. As early as 1913, Weyse and Lutz¹⁸ reported that the criterion for minimum pressure was in dispute. It should be noted that during this early period, validation of Korotkoff’s auscultatory measurement technique was accomplished primarily by comparing it with various forms of the already existing oscillometric BP measurement technique. In those early days of this century, many believed that DBP as determined by the oscillometric technique was best represented by the cuff pressure associated with the maximal oscillations in the BP cuff¹⁹ or when a marked decrease in oscillations occurred.²⁰ Today, it is generally accepted that the maximal oscillations in the BP cuff during cuff deflation occur at mean arterial pressure.²¹-²² Thus, it was often the muffling of sound that best related to the maximal oscillometric signal or to marked decreases of the signal. The controversy over the use of muffling versus disappearance in healthy, nonpregnant adults has been largely resolved with the consensus of most being that disappearance is more accurate and reliable. Unfortunately, in pregnancy, recent reviews and recommendations in the literature continue to reflect a lack of consensus regarding this issue.

In 1988, the American Heart Association noted that pregnancy was a high cardiac output state and recommended phase V unless sounds are heard to 0 mm Hg.¹⁵ The US National High Blood Pressure Education Program Working Group on High Blood Pressure in Pregnancy¹ supported recording both muffling and disappearance, with phase V disappearance being the primary indicator. This is in contrast to the British Hypertension Society,²⁴ the World Health Organization,²⁵,²⁶ and the International Society for the Study of Hypertension in Pregnancy,²⁷ in which phase IV muffling is the primary recommendation.

Reflecting the confusion of the experts, there is division in obstetric practice about the measurement of DBP. As an example, Perry et al²⁸ have reported that 48 of 91 (53%) obstetric caregivers (midwives and obstetricians) in a UK District General Hospital obstetric unit, contrary to local recommendations, used the disappearance of sound for DBP.

The results of the present study demonstrate that in most cases, disappearance rather than muffling of Korotkoff sounds more accurately reflects true DBP in pregnancy and is consistent with intra-arterial studies.²⁹-³³ Although muffling and disappearance rarely have been reported together, almost all intra-arterial studies in pregnancy show that muffling overestimates DBP sometimes by very large amounts: Ginsburg and Duncan,²⁹ 15 mm Hg; Wallenburg,³⁰ 16 mm Hg; Raftery and Ward,³¹ 11 mm Hg for phase IV and 6.6 mm Hg for phase V; Hovinga et al,³² 24 mm Hg; Brown et al,³³ 9 mm Hg for phase IV and 4 mm Hg for phase V. One can find little support in the literature for intra-arterial DBP in pregnancy being closer to muffling than disappearance. One such study was by Millsom et al,³⁴ who found muffling to be, on average, 8 mm Hg lower than intra-arterial DBP. It is unusual to find muffling (and disappearance) to be below intra-arterial
DBP. Thus, based on the literature and the present study, we feel one cannot objectively argue that, on average, muffling is closer to true DBP. To continue to do so demonstrates undue bias.

Some supporters of muffling have noted that in pregnancy there is a wider than usual difference between phase IV and phase V and have attributed this to "a systematically lower fifth sound"\(^5\) associated with the hyperkinetic circulation of pregnancy. This large difference is not uniformly found. Others have reported mean differences in pregnancy of 2.7,\(^5\) 4.5,\(^3\) 5.0,\(^5\) 6.2,\(^5\) 10,\(^8\) and 12.5 mm Hg.\(^5\) In the present study, we found a difference between DP4 and DPS that would be considered on the high end of the distribution (A1: 11.3 mm Hg; A2: 9.7 mm Hg). The results of the present study contrast slightly with our previous results in nonpregnant subjects,\(^10\) which showed that DP5, on average, overestimated K2 DBP by 3 mm Hg. Thus, the present study, which shows no statistical difference between DP5 and K2 DBP for hypertensive subjects and a 2.5-mm Hg DP5 underestimation of K2 DBP for normotensive subjects, does support the idea that in pregnancy, sounds disappear at a lower cuff pressure than in a nonpregnant state. However, it is possible that (a slightly lowered) DP5 in pregnancy may be, on average, closer to intra-arterial DBP than in nonpregnant situations.

Our data suggest that in addition to inaccuracy a major problem with the use of phase IV muffling is its lack of reliability. It is ironic that a major argument for recommending muffling over disappearance centers around the same issue. Wichman and Ryden\(^6\) have reported that in 17 of 248 (6.9%) measurements sound was heard to 0 mm Hg. The authors argue that "by definition the DP was 0 mm Hg in these cases." They go on to say "the diastolic blood pressure should be recorded at phase 4 of the Korotkoff sound to be reliable."

We feel that the evaluation of reliability and variability of muffling and disappearance should be addressed separately. Reliability can be defined as the ability to detect the presence of phase IV or phase V; variability can only be evaluated if phase IV and phase V are indeed present. If sounds are heard to 0 mm Hg (or a nonphysiological value), it should be considered that we cannot legitimately detect a phase V DBP for that particular BP determination.

In the present study, observer A1 could detect the presence of muffling 73.2% of the time in normotensive subjects and only 47.5% of the time in hypertensive subjects. Similarly, observer A2 could detect the presence of muffling 66.7% of the time in normotensive subjects and only 37.3% of the time in hypertensive subjects. Both A1 and A2 detected the presence of phase V disappearance 98.3% of the time, with sound being heard below 35 mm Hg in 3 of 58 subjects. Perry et al\(^9\) reported a 100% detection rate for phase V. The phase IV detection rate we found in the present study is lower than the 83% (83 of 100) detection rate reported by Villar et al,\(^4\) the 93% (167 of 180) detection rate reported by Clark et al,\(^3\) the 78% (39 of 50) detection rate reported by Brown and Whitworth,\(^4\) and the 76% (150 of 197) detection rate reported by Perry et al.\(^3\) The phase IV detection rate we observed in hypertensive subjects was even lower than the 58% detection rate of Villar et al\(^4\) for nonpregnant women. Although the phase IV detection rate we observed for normotensive subjects was closer to other reports mentioned above, our results strongly support the idea that the presence of a legitimate phase V is overwhelmingly more reliable than the presence of a legitimate phase IV.

When analysis was restricted to those BP determinations in which both observers agreed that phase IV was present, the interobserver variabilities of phases IV and V were similar. Thus, the large interobserver variability of phase IV lies in the inability to detect its presence reliably.

We suggest that the basic problem is related to the lack of an objective measure for the recognition of the so-called fourth phase of the Korotkoff sound. This uncertainty in the recognition of phase IV muffling is supported by the wide range found in the literature between muffling and disappearance. Investigators have reported both large and small differences between them in both pregnant and nonpregnant women. To our knowledge, the subjective evaluation of the so-called fourth phase of the Korotkoff sound has never been demonstrated. Thus, if present, the detection of phase IV muffling is imprecise and subjective and may be interpreted as a change in the quality of the sound or as a sudden reduction of sound intensity. In the present study, phase IV muffling was defined as the point of muffling rather than, or in addition to, an amplitude decrease and thus may be responsible for our lower phase IV detection rate.

Despite the fact that, on average, DP5 represents a more accurate measure of DBP than muffling and its detection is more reliable than muffling, there are individual BP determinations in which sounds are heard significantly below or above K2 DBP, indicating measurements in which muffling was closer to K2 DBP than DP5. Of the DP5 BP determinations made, 7.9% (36 of 453) of A1's and 18.9% (77 of 408) of A2's were greater than 10 mm Hg away from K2 DBP. In some measurements muffling may significantly overestimate and disappearance may significantly undervalue DP5. Thus, the problem may sometimes not be simply choosing DP4 or DP5 to be the correct measure, as there are times in pregnancy when both DP4 and DP5 do not accurately reflect DBP.

It is remarkable that even after 85 years the mechanisms of the origin of Korotkoff sounds and their relation to BP are poorly understood.\(^4\) The sounds occurring during cuff deflation have been attributed to both pressure- and flow-related phenomena.\(^4\) One may think of sounds occurring under the BP cuff as sounds generated by the physical events created by the initial opening of the compressed arterial segment (ie, when the intra-arterial pressure exceeds the cuff pressure) modulated by the resulting blood flow phenomena (eg, blood turbulence). Thus, physiological and/or physical mechanisms that modify pulsatile peripheral blood flow may modify the accuracy of the Korotkoff sound technique. For example, when there is vasoconstriction and low peripheral blood flow, sounds may disappear prematurely, resulting in an overestimation of DBP, whereas in some hyperkinetic, high cardiac output pregnancy states, flow-dependent sounds may be heard below the "true" DBP.

The flow-dependent nature of the Korotkoff sound technique may be an inherent limitation of the technique. It is difficult if not impossible for human observers to differentiate between the sounds generated by true pressure gradient reversals and the sounds gener-
ated by turbulent blood flow. Thus, in pregnancy, as in other hyperkinetic states, sounds will occasionally be present to very low cuff pressures. K2 is present whenever intra-arterial pressure increases sufficiently above cuff pressure such that a critical transmural pressure gradient (ie, intra-arterial minus cuff pressure) is achieved and the compressed segment of artery opens. K2 may develop as a result of the dynamic events created by the reestablishment of fluid contact between the proximal and distal portions of the occluded artery. The visual recognition of K2 during cuff deflation is a more specific indicator of transmural pressure gradient reversals than audible sound. Thus, K2 analysis may be particularly applicable for measuring BP in pregnancy as well as other clinical situations in which the auscultatory technique has acknowledged difficulties.

With respect to the standard auscultatory technique of measuring BP, we conclude that the disappearance of sound rather than muffling is a more accurate, reliable, and less-variable measurement of DBP in pregnancy.

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