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# Methods of assessment of the arterial pulse wave in normal human pregnancy

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**KEY WORDS**
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**Objectives:** The study was undertaken to obtain normal values for characteristics of the peripheral arterial pulse wave, in nonpregnant women and in pregnant women at three different stages of gestation, with two devices, to describe cardiovascular hemodynamic variables induced by pregnancy.
**Study design:** Sixty pregnant women were enrolled in the study at three stages of pregnancy, 17 to 20 weeks, 25 to 28 weeks, and 33 to 36 weeks gestation. Results are presented for 53 of these subjects who remained normotensive throughout pregnancy. The values measured were compared with those from 10 nonpregnant women. The two devices used were the SphygmoCor and a monitor invented and developed by Professor Edward Hon, not yet commercially available, referred to in this article as the ''Hon'' monitor.
**Results:** An increase in heart rate was observed in all pregnant women. Blood pressure values were lower in pregnancy than in normal nonpregnant women. With respect to the SphygmoCor, the time from the start of the arterial waveform to the second peak/shoulder, was significantly shorter, and augmentation pressure and augmentation index were significantly lower in pregnancy. Data obtained from the ''Hon'' monitor showed no significant differences in pulse wave arrival time, but rapid ejection time was significantly shortened in pregnancy.
**Conclusion:** The clinical findings confirm the known cardiovascular changes of pregnancy associated with vasodilatation of peripheral vessels and expansion of blood volume. The fall in augmentation pressure and index are consistent with these changes. Rapid ejection time and the time from the start of the arterial waveform to the second peak/shoulder, which should reflect similar cardiovascular physiologic events, were weakly correlated.


The value of measurement of blood pressure during pregnancy has been firmly established.[1,2] In nonpregnant subjects, examination of the characteristics of the peripheral arterial and central aortic pulse waves and pressure provides valuable information about the circulatory changes associated with hypertension and/or vascular disease.[3,4] The shape of the pressure wave contour changes (developing a sharper and narrower systolic peak) and the amplitude of the pulse wave increases during its travel along the arterial tree. Examination of the behavior of the arterial pulse wave during pregnancy

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may afford valuable insights into cardiovascular physiologic and pathophysiologic[5] features in pregnancy. In particular, earlier detection of women with, or at increased risk of preeclampsia would provide a better opportunity to introduce preventive measures than the current narrow therapeutic window available after the development of established hypertension.

Several devices for noninvasive measurement of the peripheral arterial wave or pulse wave velocity are in development, or are commercially available.[3,4,6-11] Given the use that such measurements are being shown to have in cardiovascular disease remote from pregnancy,[7,12,13] they are worthy of assessment in hypertensive pregnant women. Before the clinical usefulness of such devices can be established it is necessary to describe normal values throughout gestation.

In the current study we describe the values obtained using two of these devices SphygmoCor (Atcor Medical, West Ryde, Australia)[3,4,12] and the "Hon" monitor[9,14] in normal pregnant women at three stages of pregnancy, compared with those in a group of normal nonpregnant women. The SphygmoCor was manufactured locally and there is a lot of local expertise with its use. The Hon monitor was made available for assessment by its inventor. No financial incentives were offered by the manufacturer of either device, the entire study was investigator initiated and driven. The SphygmoCor has been extensively validated against a number of invasive hemodynamic measurements in nonpregnant subjects[15,16] but not examined in pregnancy, whereas values for the Hon monitor have been described in pregnancy[9,14,17-20] but it has never been validated against invasive hemodynamic measurements made concurrently.

The SphygmoCor consists of an applanation tonometer (a device shaped like a pencil), placed over the radial artery to acquire a set of pulse waves. The supporting software performs an analysis of the characteristics of the pulse wave obtained and calculation of central hemodynamic correlates. From these readings and simultaneously measured brachial artery pressure, central aortic pressure is calculated along with other determinants of the central aortic wave form, including augmentation pressure (AP) and augmentation index (AI),[3,4] both estimates of vascular compliance.

The Hon monitor is a device that examines the peripheral arterial circulation, but it is not yet commercially available.[9] A transducer is applied to the finger of one hand and an electrode connected to a finger of the other. Both leads are needed to acquire the electrocardiogram (ECG) that is used for timing in the cardiac cycle. The peripheral pulse wave is recorded, and several components of associated central hemodynamic events are calculated as previously described by Hon et al,[14] including rapid ejection time (RET) and pulse wave arrival time (PWAT).[9]

## Material and methods

### Subject selection

All studies were approved by the Human Research Ethics Committee of Royal North Shore Hospital, and all subjects gave written informed consent to participate.

Sixty pregnant women attending Royal North Shore Hospital for routine antenatal care, and 10 nonpregnant women were incidentally selected to participate in this study. Of the 60 pregnant women, 20 were studied at each of 17 to 20 weeks, 25 to 28 weeks, and 33 to 36 weeks of gestation. All women studied were between the ages of 22 and 44 years.

### Clinical and pulse wave measurements

Subjects were randomly assigned to two groups, using a table of random numbers.[21] The first group was tested with the SphygmoCor and then the Hon monitor. The second group was tested with the Hon monitor first and then the SphygmoCor. All women rested for approximately 10 minutes before the measurements.

All measurements were made by the same observer. After an initial learning period (approximately 20 repeated measurements) satisfactory reproducibility was achieved (less than 5% variability between duplicate measurements). The SphygmoCor program has a quality control feature incorporated in its software and displayed on the measurement screen (upper right-hand corner), whereas quality control parameters were calculated manually from repeated measurements when using the Hon monitor.

### SphygmoCor measurements

Brachial blood pressure (systolic and diastolic, Korotkoff phases I and V) was recorded in the SphygmoCor software.

Using the tonometer, a radial artery pulse wave reading was made according to the manufacturer's instructions (the tonometer is connected to the laptop that incorporates the SphygmoCor program). Calculated parameters include the following (Figure 1, *A*)[22]:

1. Central aortic pulse wave contour
2. Central aortic systolic and diastolic blood pressure
3. Central pulse pressure
4. Time to first aortic peak ($T_1$)—time from the start of the waveform to the first peak/shoulder
5. Time to second aortic peak ($T_2$)—time from the start of the waveform to the second peak/shoulder
6. AP—the pressure difference between the first peak/shoulder ($T_1$) and the second peak/shoulder ($T_2$)
7. AI—the augmentation pressure divided by the central pulse pressure (AP/PP)

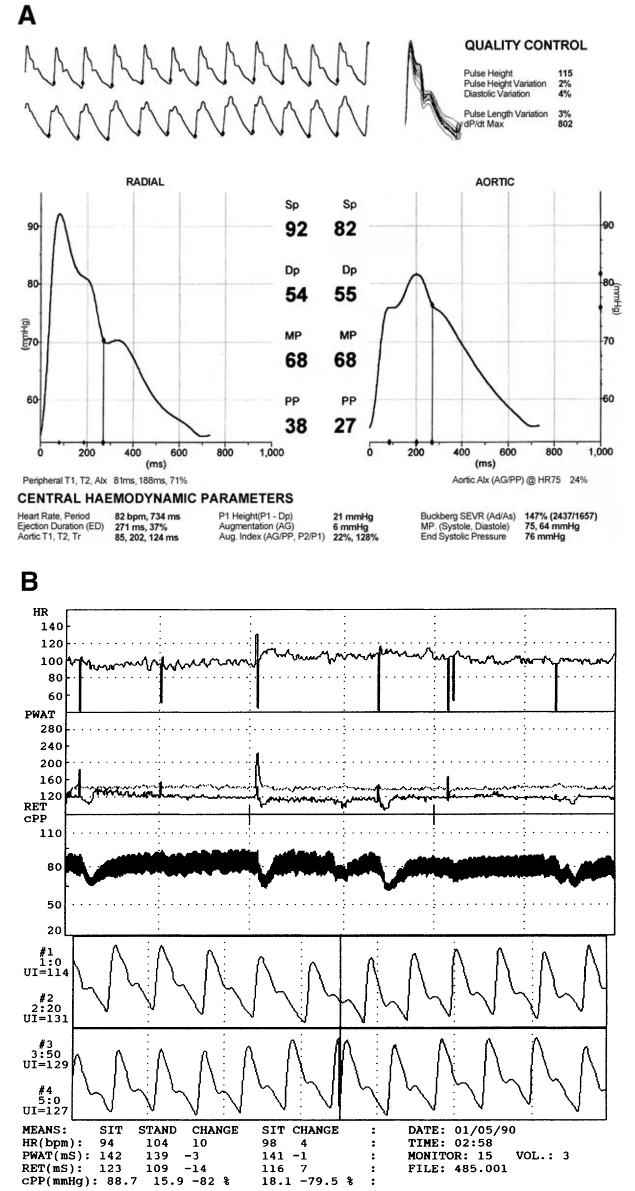



**Figure 1** **A**, The SphygmoCor data sheet provides information concerning the radial pulse wave contour acquired as well as a central pulse wave contour and blood pressure measurements. AP and AI are also provided. **B**, The datasheet provided by the Hon monitor software shows heart rate *(HR)*, rapid ejection time *(RET)*, and pulse wave arrival time *(PWAT)* measurements obtained throughout a 6-minute test. For comparison with SphygmoCor values, calculations from the first 2 minutes were used.

## Hon monitor measurements

The transducer was attached to the left ring or middle finger and the ECG lead to the right ring finger or right side of the subject's precordium. The pulse wave generated from the digital transducer was recorded.

Calculated parameters, timed with the concurrently measured ECG incorporated into the software, include the following (Figure 1, *B*):

1. PWAT—the time taken for the pulse wave to reach the digital artery
2. RET—the time from the start of the pulse wave to its maximum height

## Statistical methods

Group data are presented as mean ± SD. Between-group differences were compared by unpaired *t* tests, within-group relationships analyzed by analysis of variance. A *P* value less than .05 was considered to be of statistical significance.

# Results

Fifty-three of the 60 pregnant women studied remained normotensive throughout pregnancy, whereas 3 women had preeclampsia develop and 4 had gestational hypertension. Results for these 7 subjects have been excluded from analysis. None of the subjects had gestational diabetes mellitus develop. Demographic details and clinical findings are shown in the Table. Age and height were comparable in all groups. As expected, weight and body mass index increased in pregnancy, and there was a greater fall in brachial diastolic blood pressure than systolic blood pressure. Heart rate was increased in all pregnant subjects.

## SphygmoCor

The SphygmoCor calculated values are shown in the Table. As for brachial blood pressure, aortic systolic and diastolic blood pressure was lower in pregnancy than in nonpregnant women.

Aortic $T_2$ was significantly shorter in all pregnant groups. AP and AI were also lower in pregnancy compared with healthy nonpregnant subjects.

## Hon monitor

There were no significant differences amongst the clinical groups with respect to PWAT (Table). RET was significantly shortened in pregnant subjects ($P < .05$).

## Comparable estimates from the two devices

RET and $T_2$ should be estimates of the same physiologic event in the cardiac cycle, both related closely to heart rate. There was a weak correlation between them ($r = 0.255$, $P = 0.047$) (Figure 2).

# Comment

Our findings confirm that heart rate increases, blood pressure falls, and the pulse pressure widens in normal pregnancy. It has been shown that these phenomena are due to a combination of vasodilatation and volume

**Table** Hemodynamic parameters (mean ± SD) calculated by the SphygmoCor and Hon monitor

| | | Weeks' gestation | | |
|---|---|---|---|---|
| Parameter | Nonpregnant | 17-20 | 25-28 | 33-36 |
| Age (y) | 33.5 (6.1) | 32.3 (3.6) | 30.8 (5.1) | 31.5 (3.2) |
| Height (cm) | 160 (7.2) | 164 (6.3) | 163 (7.1) | 164 (5.7) |
| Weight (kg) | 58.6 (5.9) | 63.4 (8.3) | 67.7 (8.5)* | 75.0 (9.0)† |
| Heart rate (beats/min) | 69 (11.0) | 80 (8.3)* | 86 (10.0)† | 93 (8.1)† |
| Radial systolic blood pressure (mm Hg) | 111 (6.9) | 103 (9.0)‡ | 107 (11.6) | 108 (10.0) |
| Radial diastolic blood pressure (mm Hg) | 71 (8.9) | 57 (8.7)† | 60 (9.3)* | 65 (7.8)‡ |
| Aortic systolic blood pressure (mm Hg) | 101 (7.0) | 89 (8.0)† | 91 (8.9)* | 94 (9.7) |
| Aortic diastolic blood pressure (mm Hg) | 72 (8.9) | 59 (8.6)† | 61 (8.9)* | 67 (8.0) |
| PWAT | 183 (41.1) | 176 (25.8) | 172 (33.5) | 163 (15.1) |
| RET | 146 (38.9) | 115 (20.4)‡ | 119 (18.3)‡ | 120 (11.5)‡ |
| Aortic $T_1$ | 106 (10.1) | 103 (16.4) | 109 (17.8) | 109 (13.8) |
| Aortic $T_2$ | 220 (15.7) | 201 (21.8)‡ | 196 (15.6)* | 186 (12.7)† |
| AP | 6.1 (3.1) | 4.4 (3.2) | 3.1 (3.2)† | 2.9 (2.5)* |
| AI | 21 (9.0) | 14 (7.6)‡ | 10 (9.8)* | 10 (8.8)* |

* $P<.01$ compared with nonpregnant values.
† $P<.001$ compared with nonpregnant values.
‡ $P<.05$ compared with nonpregnant values.

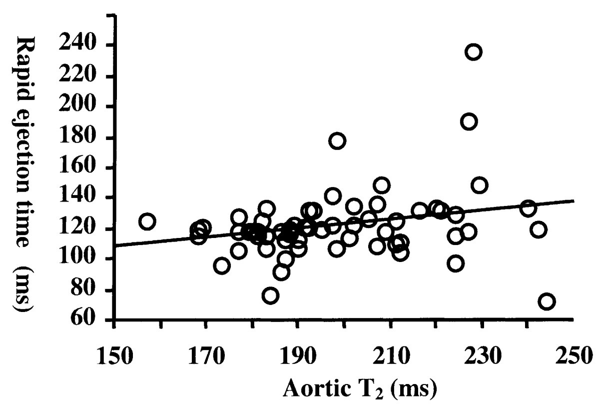
expansion.[1,5] The calculated decline in central systolic and diastolic blood pressure are consistent with these physiologic responses to pregnancy.

The young female nonpregnant subjects studied had low augmentation indices (Table), and during pregnancy there was a further significant fall in both AP and AI ($P<.01$), indicating vasodilatation.

In contrast to this, nonpregnant subjects with large vessel disease (eg, hypertension, diabetes, renal failure) have reduced arterial compliance that causes a rapid and enhanced reflection of the propagated arterial pulse wave back toward the heart. A similar finding is characteristic of aging. This in turn is evident as an increase in AP and AI in those subjects.[3,12,13]

The PWAT was not significantly altered in pregnant subjects. The increase in stroke volume and shortened ejection time accepted as normal accompaniments of pregnancy would, if uncompensated, be expected to cause a shortening of PWAT. The absence of this shortening is in turn consistent with concomitant compensatory generalized vasodilatation in pregnancy, reflecting an increase in arterial compliance. The shortening of RET and $T_2$ are both consistent with relative tachycardia, and this together with unchanged PWAT, indicates the presence of an increased left ventricular ejection fraction.[5]

Both devices tested gave information confirmatory of the hemodynamic alterations previously described in normal pregnancy. Both are easy to use in the outpatient clinic setting without a need for expensive specialized equipment. The measurements calculated are estimates of different although related hemodynamic events. The two most comparable measures are RET and $T_2$, which are weakly correlated (Figure 2). This may be related to




Y = 62.486 + .303 * X; r=0.255, p<0.05

**Figure 2** Rapid ejection time versus the time from the start of the waveform to the second peak/shoulder (aortic $T_2$). A weak correlation ($r = 0.255$, $P<.05$) is evident.

the wider range of RET measurements and lack of a quality control device within the Hon monitor, compared with the quality control of the SphygmoCor seen in the upper right-hand corner of Figure 1, *A*.

Our current work is aimed at assessing whether there are changes in the measured waveforms and calculated central pressure determinants in women with hypertension in pregnancy. We are investigating the hypotheses that in preeclampsia, vasoconstriction will result in a specific increase in AP and AI and that their changes precede the clinical disorder. Should this turn out to be the case, measurements such as those described in this report could become generally useful as screening procedures in women at increased risk of preeclampsia.

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