Cardiac Output in Pregnancy
Correlation Between Evans Blue Dye and Blood Pressure Methods
By CHARLES H. HENDRICKS, M.D. AND EDWARD J. QUILLIGAN, M.D.

Cardiac output estimations done by the pulse pressure method were compared to those done simultaneously by the dye method in pregnancy, labor, and in the early puerperium. The subjects selected were young, healthy and without edema or clinical evidence of heart disease. A total of 30 determinations was carried out on 23 subjects. Agreement within 25 per cent of the dye method was attained in 90 per cent of the blood pressure method tests.

In initiating a study of the rapid alterations in cardiac output occurring during labor and the puerperium, it appeared desirable to find a simple method whereby repeated estimates could be made during a very short period of time. The majority of work to date reporting cardiac output and related functions at various stages of pregnancy lists single output determinations or, at best, determinations repeated only at relatively long intervals for any single individual. While such comparatively isolated observations are of interest, they have failed to yield a significant amount of information concerning the cardiovascular effects of, for example, such important phenomena as a single vigorous uterine contraction, or the separation of the placenta from its uterine attachment.

This paper reports our efforts to test the validity of the pulse pressure method of calculating cardiac output on patients in late pregnancy, labor, and the puerperium. The early historical background of this method will not be reviewed, inasmuch as it has been surveyed in rather thorough fashion by Starr and his associates in 1954, who evolved the following equation for more accurately relating pulse pressure to stroke volume:

\[
\text{Stroke volume (cc.)} = 90.97 + 0.54 \text{ pulse pressure (mm. Hg)} - 0.57 \text{ diastolic pressure (mm. Hg)} - 0.61 \text{ age (years)}.
\]

With this formula, they attained an error in computation of the stroke of less than 5.9 cc. in two thirds of the estimates. No correction was found necessary for body size. A most important factor in the equation, however, is that of patient age.

Remington and associates derived a series of factors for the prediction of stroke index which give simultaneously a smaller volume equivalent at higher pressure levels. They did not incorporate an "age factor" in their formula, but they were concerned enough about the effect of body mass to include the factor of body surface in their calculations. Although they were not seriously proposing the use of their adaptation as an accurate clinical technic, it seemed worthwhile to explore its applicability in the group of patients we wished to study.

Initially, we wished to eliminate as far as possible the variables which had been of concern to previous workers who had attempted to apply such methods to the general population. Consequently, the subjects selected were to be free of gross obesity, edema, or clinically evident heart disease. They were to be young healthy patients in late pregnancy, during labor, or in the early puerperium.

EXPERIMENTAL PROCEDURE

The study was carried out on 23 in-patient subjects, seven of whom were studied more than once. All but three ranged between fifteen and twenty-two years. Four were pregnant but not in labor, six were in various stages of labor, and thirteen were postpartum. Pressure from a brachial artery was recorded directly by a Sunborn electromanometer.

In the first nine studies, after an initial arterial blood pressure reading had been made, the electro-
The manometer was disconnected, and a carefully weighed amount of Evans Blue dye (usually nearly 25 mg.) was injected rapidly into a contralateral antecubital vein. Arterial samples were collected at two-second intervals, using a Rothe sample collector. The manometer was then reconnected, and further blood pressure records were made. As the study progressed, it became evident that fairly marked changes could be anticipated in cardiac output at various phases of uterine contraction, making it difficult to insure good reproduction of the conditions existing from the time at which the pulse pressure determination was made to the time when the dye test was run. This difficulty was mitigated to some degree by the use of a multiple lead externally recording tokodynamometer which gave visual evidence as well as a printed record of the state of uterine contractility at the time each test was carried out. In the last 21 of the 30 determinations, Courmand needles were placed in both brachial arteries, in order that the dye and pulse pressure observations might be truly simultaneous.

The blood pressure values were determined by averaging from one to five series of four consecutive systolic and diastolic pressures, respectively. After incorporating the Remington volume factor, cardiac output was determined as follows:

\[
\text{CARDIAC OUTPUT} = (\text{systolic volume factor} - \text{diastolic volume factor}) \times \text{heart rate} \times \frac{\text{body surface}}{c \cdot DF}\]

Patients who were immediately postpartum were reweighed, and body surface calculated according to the new (postpartal) weight.

Evans Blue in the two-second samples was determined on 0.2 or 0.3 ml. of plasma diluted in saline to a volume of three ml. Readings were carried out in a Beckman Model B spectrophotometer against a plasma blank at a wave length of 610. The optical density of the dye standard (1.0 ml. of T-1824 diluted 1:500) was known; the same numbered lot of dye was used throughout the series. Having determined the hematocrit, the cardiac output was then calculated thus:

\[
\text{Cardiac output} = \frac{\text{Dye injected} \times ODs \times 500 - 60}{c \cdot DF \times 1000} \times \frac{\text{body surface}}{c \cdot DF}
\]

Where
- \(ODs\) = optical density of 1 ml. of dye diluted 1:500.
- \(c\) = sum of optical densities before recirculation.
- \(DF\) = dilution factor.

\[
\text{Cardiac output} = \frac{\text{Cardiac output}}{\text{blood}} \times \frac{\text{plasma}}{(1 - HCt)}
\]

Repeated studies were carried out upon seven patients as follows:

(a) At rest vs. post-exercise in 4 postpartum patients.
(b) Active labor, at varying phases of uterine contraction in 2 patients.
(c) In one postpartum patient, an initial test was run when the patient appeared to be somewhat less apprehensive. A second test was done after she appeared to be somewhat less apprehensive.

**RESULTS**

Of the 30 determinations, 27 (90 percent) of the cardiac output determinations as measured by the blood pressure method agreed with the dye-measured outputs within 25 percent (fig. 1). It may be seen from table 1 that an approximately equal degree of agreement was obtained whether the patient was pregnant but not in labor, actually in labor, or postpartum. In the studies which were repeated in the same individual, the degree of variation of one method from the other was surprisingly close in five out of the seven cases.

**DISCUSSION**

The original anticipation had been that it might be possible to devise a new "correction factor" which might increase the accuracy of the blood pressure method of cardiac output as applied to pregnant patients. The necessity of such a correction factor, however, is not suggested by examination of the results, since the blood pressure method determinations fall almost equally above and below the line in figure 1. The mean variation of the blood pres-
sure method from the dye method was $-3.9$ per cent.

There is some question as to whether the postpartum rather than the antepartum weight should be employed in figuring the body surface. It might be suspected that the cardiovascular system of the patient in the early puerperium functions more in accordance with her recent antepartum weight than in accordance with her newly acquired postpartum weight. In the current series, for example, calculation of body weight in terms of the antepartum weight for the patient who is actually postpartum would have raised the blood pressure method cardiac output by about three per cent. Incorporating this change into the results listed in table 1 would have reduced the mean variation of the blood pressure from the dye method to the neighborhood of 2 per cent.

**Summary**

Cardiac output estimations done by the blood pressure method were compared to those
done by the dye method in pregnancy, labor, and in the early puerperium. A total of 30 determinations were carried out on 23 subjects. Agreement within 25 per cent of the dye method was attained in 90 per cent of the blood pressure method tests.

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