

FOETAL CEPHALOMETRY BY ULTRASOUND

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To ascertain the size and to observe the growth of the foetus *in utero* are matters of great importance to the obstetrician, yet the methods hitherto available have been either imprecise or of limited application. Practically the only part of the foetus which can be measured is the head; this measurement has been made by X-rays with varying reliability.

The use of the ultrasonic echo-sounding technique described here has, we believe, advantages over radiography.

THE PLACE OF FOETAL CEPHALOMETRY IN OBSTETRICS

The cardinal importance of knowledge of the size and shape of the foetal head in order to understand the mechanism of labour was recognized by Smellie (1752), who also pointed out that it is the biparietal diameter which passes through the narrowest part of the brim of the pelvis. Denman (1795), in advocating the induction of premature labour in cases of contracted pelvis, regretted that it was impossible to make accurate measurements on which to base the indications for the operation. "It would be highly satisfactory", he wrote, "if I were able to state with precision the exact dimensions of the cavity of the pelvis . . . to enable us by them to form an unerring guide to practice: and as the head of a child before it is born can never be accurately measured, of course the exact relation between them must be unknown, and the determination must be therefore left to opinion."

In more recent times numerous methods of X-ray cephalometry have been developed. Cephalometry has been used for two main reasons:

- (1) To assess disproportion.
- (2) To assess the growth and maturity of the foetus.

Scammon and Calkins (1922, 1929) and Reece (1935) were among the earliest workers to use cephalometry as an index of foetal growth and maturity. They stated that the biparietal diameter increased by 2.5 mm. a week.

More recently Crichton (1952, 1953), Macdonald (1952, 1954) and Glass (1956) have stated that the foetal biparietal diameter increases by about 1 mm. a week in the last 4 weeks of pregnancy. Moir (1943, 1946, 1949, 1956) has devoted a great deal of work to X-ray cephalometry and believes it to be valuable in the assessment of disproportion and the likely outcome of labour.

Despite the work which has been done on the subject, many obstetricians remain unconvinced of the value of X-ray cephalometry. Savage (1951) was of the opinion that the head could not be measured accurately *in utero*. Mengert and Korkmas (1957), with an extensive experience of obstetric radiology, gave up measuring the head altogether and contented themselves with a clinical impression as to whether the head was large, medium or small.

Crichton (1962) in his William Blair Bell Memorial lecture on "The Accuracy and Value of Cephalo-pelvimetry" reviewed the work of

9 years, first at Oxford, then at Durban, assessing over 3,000 cases. He stressed the value of the biparietal diameter as the most important measurement of the foetal head and, in particular, he showed that its significance is superior to that of the average cranial circumference—the method advocated by Ball (1935, 1936). Crichton prefers intra-partum to antenatal cephalo-pelvmetry because in labour the head is usually fixed. “Unfortunately”, he says, “the biparietal diameter of any high head—which one associates with brim disproportion—has a tendency to present unfavourably in this (i.e., the lateral) radiograph. Thus only 33 per cent of unmodelled biparietal diameters presented, or could be deduced fairly accurately from antenatal radiography in the present series.” This statement shows the severe limitations of the radiological method.

To know the size of the foetal head in cases of suspected disproportion and in malpresentations, and to observe by repeated measurements the growth of the foetal head in normal and abnormal pregnancy would be more than worth while. In cases complicated by placental degeneration due to pre-eclampsia, chronic nephritis or hypertension, in cases of ante-partum haemorrhage, in diabetes, or in any other condition where it may be desirable in the interests of the foetus to terminate the pregnancy prematurely, knowledge of the size of the child, of which the size of the head is an indirect index, would be of great value, and any indication of reduced rate of growth would be even more important. A small foetus may be starving from placental failure; similarly, the presence of a well-grown foetus in a case of, say, hypertension, might lead the obstetrician to conclude that “placental insufficiency” was not a feature of the case.

Butler (1962) stated that one-third of all “premature” babies weighing 2.5 kg. or less were born at 39 weeks or more of gestation, and that these babies had a mortality rate 2½ times the average. Sjostedt *et al.* (1958) used the term “dysmature” to describe such infants. The cause of death in cases of “placental insufficiency” has often been ascribed to anoxia, but evidence is accumulating to suggest that lack of oxygen is only part of the picture. It seems likely that these babies starve to death in the

same way as an adult does when deprived of food, and it is possible that they may actually begin to lose weight *in utero*.

All that the obstetrician can do at present is to observe all cases in whom (whether due to toxæmia or other factors) there appears to be failure of foetal growth and hope to intervene at the right time. The purpose of ultrasonic cephalometry in these cases is to demonstrate whether or not adequate foetal growth is taking place and whether the growth rate is altering.

Clinical estimation of the size of a baby is little more than guesswork. The thickness of the abdominal wall, the tension of the uterus, the amount of liquor amnii and the presentation and attitude of the foetus are liable to influence judgment.

A method of measuring the biparietal diameter of the foetus *in utero* by pulsed ultrasound has been evolved by us during the last 3 years, and has already been briefly described (Donald and Brown, 1961; Willocks, 1962a, b).

PRINCIPLE OF THE METHOD

The basis on which the measurements are made is as follows. The foetal head, in horizontal plan view, is ovoid, with only two pairs of parallel surfaces—between the brow and occiput and between the two parietal eminences.

A beam of ultrasound passing through the foetal head is partially reflected by the skull margins and by discontinuities in density within the brain. A given echo will return along the path of the ultrasonic beam to the originating probe only when its axis is at right angles to the reflecting surface. Opposing skull margins will, therefore, produce simultaneous echoes of maximum amplitude only when the beam axis lies along either the occipito-frontal or the biparietal diameter (Fig. 1).

Tests with a dry foetal skull in a water tank proved that echoes from both sides of the skull were obtained with simultaneous maximum amplitude only when the ultrasonic beam traversed the diameters described above. This observation was also checked by work on the heads of newborn infants.

The foetal biparietal diameter is usually more or less at right angles to the anterior surface of the maternal abdomen and is, therefore, readily

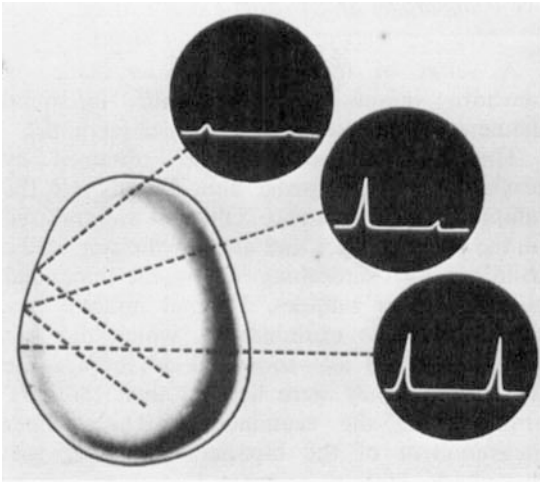


FIG. 1a

Superior or plan view of skull with ultrasonic echo display. Echoes have maximum amplitude when beam of ultrasound is directed along the biparietal diameter, but not otherwise. This serves to identify the biparietal diameter as well as to measure it.

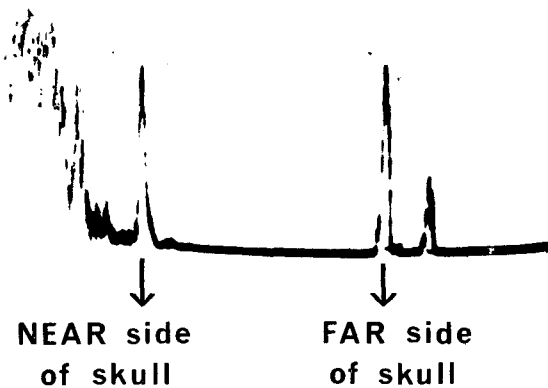


FIG. 1b

Appearances in an actual case.

accessible to a searching ultrasonic beam generated by a transducer probe placed on the abdominal wall. The occipito-frontal diameter is less accessible because of its lateral position and is so much larger than the biparietal diameter that it is unlikely to be confused with it.

TECHNIQUE

The apparatus used is a modified commercial ultrasonic flaw detector (the Kelvin Hughes Mark IV), with "A-scope" presentation and a

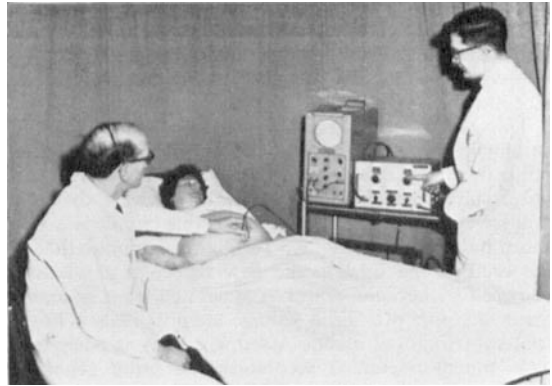


FIG. 2

The apparatus in use.

pecially constructed ranging unit to measure accurately the time of flight of a pulse of ultrasound reflected from an interface where there is a discontinuity in acoustic impedance of the tissues such as skull/brain and brain/skull. (Specific acoustic impedance is represented by the product of tissue density and velocity of sound wave transmission.)

The frequency used for cephalometry is $2\frac{1}{2}$ megacycles per second. The apparatus is portable on a trolley and is used at the bedside. For the patient the examination is simple and free from discomfort, merely entailing smearing the abdomen with olive oil to secure acoustic coupling and scanning over the region of the foetal head with the small probe unit (Fig. 2).

An electrical pulse at a frequency of 50 cycles per second discharges through a thyatron circuit a condenser charged to a high voltage. This condenser is in series with one of a pair of piezo-electric crystals mounted side by side in the probe unit. The pulse applied 50 times a second therefore to this crystal causes it to vibrate for a few microseconds at a frequency determined by the elastic properties and thickness of the crystal. The sound energy is thus radiated from the transducer surface in a narrow pulsed beam. Discontinuities of specific acoustic impedance in the path of the beam give rise to partial reflection of the ultrasound and if the discontinuity has a surface parallel to that of the transducer, and therefore at right angles to the incident beam, some of the energy is reflected back along the probe axis and strikes the receiving transducer crystal. A small voltage is generated by the piezo-electric effect, amplified and displayed as vertical deflections or "blips" on a horizontal linear time-base sweep on a cathode ray tube, the propagating source of ultrasound being represented at the origin of the sweep. The time-base of the oscilloscope is also started by the master pulse firing the thyatron. Thus the

reflecting surface of a discontinuity in impedance is indicated on the oscilloscope trace as a "blip" displaced along the trace by a distance proportional to the time between transmission of the ultrasound pulse and reception of the echo.

This distance is measured by the ranging unit by employing two electronic cursors as follows: The master pulse from the flaw detector starts the run-down of a linear phantastron sweep generator, which drives a multiar comparator. The output of this circuit is a very short pulse applied as "Z" (brightness) modulation to the oscilloscope tube in the flaw detector; a reference voltage for the comparator is generated by a potentiometer across a stabilized voltage supply. Thus a bright spot superimposed on the A-scope display is positioned by a potentiometer. A second similar pulse generator is also incorporated. This can be triggered either by the master pulse or by the pulse from the first timing unit. Thus two bright markers are available for measurement on the A-scope trace and are positioned by two potentiometers scaled in units of time. If the material under examination is homogeneous (i.e., the velocity of the sound pulses is constant) the time measurement will be proportional to the distance and the measuring dials can be scaled in units of distance.

DEVELOPMENT OF THE METHOD

It is believed that the major echo-producing surfaces of the foetal head are the sides nearer to the probe of the proximal and distal walls of the skull. The time interval measured between echoes from the opposing sides of the foetal head is therefore represented as the difference between the time taken for the ultrasonic reflections to reach the probe from the outer reflecting surface of the proximal side of the skull and the inner reflecting surface of the distal side of the skull. This time is less than that which would represent the actual biparietal diameter by the thickness of the scalp at the proximal side of the skull plus the thickness of scalp and skull at the distal side.

To obtain an estimate of the biparietal diameter in units of distance, the speed at which ultrasound travels in the foetal head requires to be known. With this end in view, two experiments were designed:

- (1) To compare the time taken by ultrasound to traverse the biparietal diameter in the newborn with the actual measurement of that diameter.
- (2) To estimate the proportion of the various components—scalp, skull and brain—in the foetal head.

(1) *Comparison of Ultrasonic and Calliper Measurements of the Neonatal Head*

A series of measurements was made on newborn infants to obtain the biparietal diameter by ultrasonic and calliper methods.

The ultrasonic results were obtained by placing the small probe unit directly on the infant's parietal eminence. Olive oil was smeared on the probe surface and also on the side of the child's head, smoothing down the hair and eliminating air bubbles. Normal infants were chosen for this examination, which did not disturb them at all—some did not even rouse from sleep. They were held in their mothers' arms during the examination. The calliper measurement of the biparietal diameter was then made, without previous knowledge of the reading obtained by ultrasonic examination.

The results of this series are summarized in Table I.

In 73.5 per cent of cases examined the error was 1 mm. or less.

(2) *Estimation of Thickness of Scalp and Skull in the Mature Foetus*

The thicknesses of the skull and of the superficial tissues in the region of the parietal eminences were measured separately with a

TABLE I
Biparietal Diameter in the Neonate; Calliper and Ultrasonic Measurements

Number of cases examined	72
Average external biparietal diameter (measured by calliper)	9.30 cm.
Average time measured by ultrasound (probe surface to distal skull margin)		117.8 μ s

From these data a scale factor can be applied to individual measurements of time (t) to predict the biparietal diameter (d):

$$\begin{aligned} \text{i.e., } d \text{ (cm.)} &= 9.30/117.8 t \text{ (}\mu\text{s)} \\ \text{i.e., } d &= 0.079 t \end{aligned}$$

The error is the difference between the calliper measurement and that calculated from the above equation. These errors were calculated and show a distribution as follows:

Error	Number of Cases
Less than 0.5 mm.	31 (43%)
Between 0.5 and 1.0 mm.	22 (30.5%)
Between 1.0 and 1.5 mm.	9 (12.5%)
Between 1.5 and 2.0 mm.	(4%)
Greater than 2.0 mm.	7 (10%)

micrometer in a series of 18 post-mortem specimens, all being infants weighing over 2,000 grammes and without cranial abnormality. The average thickness of the skull was 0.13 cm. and of the scalp 0.12 cm. (This measurement for the skull is more than that quoted by Macdonald (1954) who, in a similar investigation, found that the skull of the mature foetus was just under 0.1 cm. thick.)

These data have permitted the velocities of ultrasound in the various components of the neonatal head to be resolved. The velocity in soft tissues including brain was found to be 1,525 metres per second. Ludwig (1950) and Edler (1961) quote the velocity of ultrasound in the adult brain as 1,515 metres per second, a figure that is in good agreement with that obtained by us.

(3) Application to Foetal Measurements

Assuming the post-mortem data to be relevant, and the skull and scalp thicknesses to be proportional to the biparietal diameter, we can estimate the biparietal diameter (d) from the difference in the time of arrival of sound pulses from the skull margins (tf) by means of the equation:

$$d \text{ (cm.)} = 0.080 \text{ } tf \text{ } (\mu s)$$

This relationship is slightly different from that given for the neonatal head since the foetal measurement is made between the skull margins and not between the probe surface and the distal margin (i.e., the foetal measurement is less than the neonatal by the thickness of the scalp on the side nearest the probe).

A measurement of time in microseconds representing the distance apart of the echoes from the proximal and distal skull walls can thus be converted to centimetres by applying the scale factor 0.080.

DISCUSSION OF RESULTS

As has been shown above, in about three-quarters of all cases the estimate of the neonatal biparietal diameter by ultrasound differed by 1 millimetre or less from the calliper measurement taken at the same time.

The accuracy of the method for measurements *in utero* can be roughly assessed from the data for 25 cases measured on 4 or more

occasions. In the last trimester of pregnancy the biparietal diameter may be regarded as increasing linearly with time. Thus eliminating by linear regression the variation attributable to changes of the diameter with time we can estimate the average standard error of an observation to be 0.13 cm. or about 1.5 per cent of the mean late pregnancy value. This figure is likely to underestimate the accuracy of the measurements, as all deviations from the linear trend, including aberrations of growth, are regarded as errors of measurement.

Another way of checking the relevance and accuracy of measurements *in utero* is to compare the ultrasonic estimate prior to delivery with the postnatal calliper measurement. This has been done in 53 cases for which the last ultrasonic measurement was not more than 14 days before delivery (mean 3.9 days) and the calliper measurement was taken not more than 9 days after delivery (mean 2.6 days). The high correlation (0.88) found between these two sets of measurements is very reassuring considering that the measurements were not taken at standard times before and after the delivery. The correlation does not, however, signify that the last antenatal and the postnatal measurements are in close agreement. In 49 out of the 53 cases the postnatal measurement was smaller. The mean difference between the last ultrasonic estimate and the postnatal calliper measurement was 0.48 cm. with a standard deviation of 0.29 cm.; the largest observed difference was 1.12 cm. This result means that either the ultrasonic method overestimates the biparietal diameter or that the diameter changes after delivery. Since there is no relation between the difference of the two measurements and the time (in days) at which the calliper measurement was taken, the change, if genuine, must occur shortly after delivery.

Examination of 25 cases by calliper at short intervals after the delivery showed that the biparietal diameter usually decreased in the first 24 hours of life. Figure 3 illustrates typical changes before and after birth in 4 of these cases in which a number of antenatal measurements were also available.

By contrast, daily calliper measurements of the biparietal diameter of 38 newborn infants during the second to sixth day of life (i.e., after

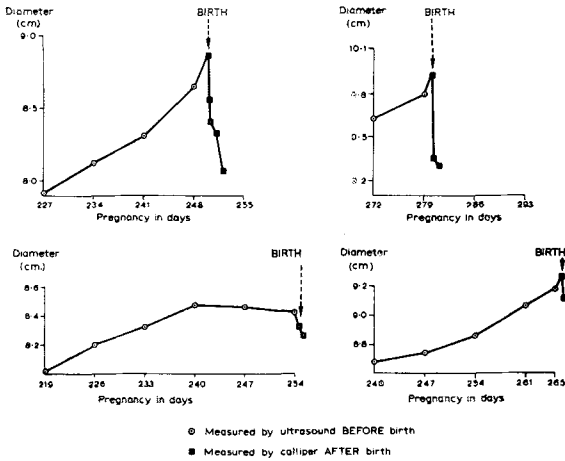


FIG. 3

Variation of biparietal diameter before and after birth.

the first 24 hours) showed in 23 cases, variations less than 0.1 cm. and in a further 4 cases variations less than 0.2 cm.; of the remaining 11 cases, 3 showed a steady growth of about 0.3 cm. in 5 days and 4 showed a similar decrease; in only 4 cases was there a variation of more than 0.3 cm. and there was reason to believe that these were due to errors in observation.

The reasons for the major alteration observed in the biparietal diameter during the first day of life are obscure. It had been expected that the heads of infants delivered vaginally would increase in size as moulding passed off, and that those delivered by Caesarean section while

the head was still above the pelvic brim would remain unchanged. It was found, however, that the change was not related to the method of delivery. The decrease might be attributable simply to the effects of nursing with the baby lying on its side.

Ultrasonic estimates of the biparietal diameter of the foetal head have been made in more than 400 antenatal patients in the Glasgow Royal Maternity Hospital, but many of these are imperfectly documented because they were emergency admissions, because they were not eventually delivered in the hospital or because they were examined before the method was fully established. For 209 cases details of maternal characteristics such as age, parity and height as well as the notes concerning complications of pregnancy and its outcome are available. Of these cases, 73 were measured on more than one occasion. The 209 cases were divided into four clinical groups: cases with albuminuric pre-eclampsia, cases with hypertensive complications, cases with ante-partum haemorrhage including placenta praevia and the remaining cases consisting predominantly of uneventful pregnancies or cases with incidental complications such as a cardiac lesion, diabetes or anaemia.

Table II shows the distribution of cases according to clinical group and to the number of measurements. It also shows that the group for which two or more measurements were available was rather heavily loaded with "cases of clinical interest"; even in the remainder, 23 out of the 42 cases had incidental complications.

TABLE II
Distribution of Cases by Clinical Group and Number of Measurements

Clinical Group	Number of Measurements				
	One	Two	Three	Four or More	Total
Albuminuric pre-eclampsia	6	3	—	1	10
Hypertensive complications	29	2	5	2	38
Ante-partum haemorrhage including placenta praevia ..	19	7	4	7	37
Remainder:					
Incidental complications	12	6	7	10	35
Uneventful	70	11	3	5	89
	136	29	19	25	209

Attention will be drawn to this limitation of the longitudinal data. The results discussed below apply to measurements taken within the last quarter of pregnancy.

Foetal Weight

In complications of pregnancy the decision to induce labour before term is to some extent influenced by the assessment of foetal size. The relationship between birth weight and the ultrasonic measurement of the biparietal diameter taken not more than 7 days before delivery was examined on 152 cases. The two measurements were found to be highly correlated (0.77): the regression equation of birth weight on the biparietal diameter (D) was

$$\text{Birth weight (ounces)} = 30 \times D \text{ (cm.)} - 177$$

with a standard error of the estimate of 16 ounces. This indicates that in about two-thirds

of the cases we can estimate foetal weight to within ± 1 pound. For clinical purposes, however, one is rather more interested in determining whether the foetus is not unduly small than in estimating its weight. A simple rule will serve this purpose: if the ultrasonic measurement of the biparietal diameter is 8.5 cm. or more the baby is unlikely to weigh less than 4 pounds, if the diameter is 9.0 cm. or more the expected weight of the baby is 5 pounds or over. Both these statements can be made with the expectation of being right in over 80 per cent of cases. Figure 4 shows the bivariate distribution of birth weight and foetal biparietal diameter and the regression line. The "step-like" line illustrates the rules given above: of 141 cases with diameter values greater than 8.5 cm. only 2 were below 4 pounds in weight, and of 129 cases with diameter value above 9.0 cm. only 4 were below 5 pounds in weight.

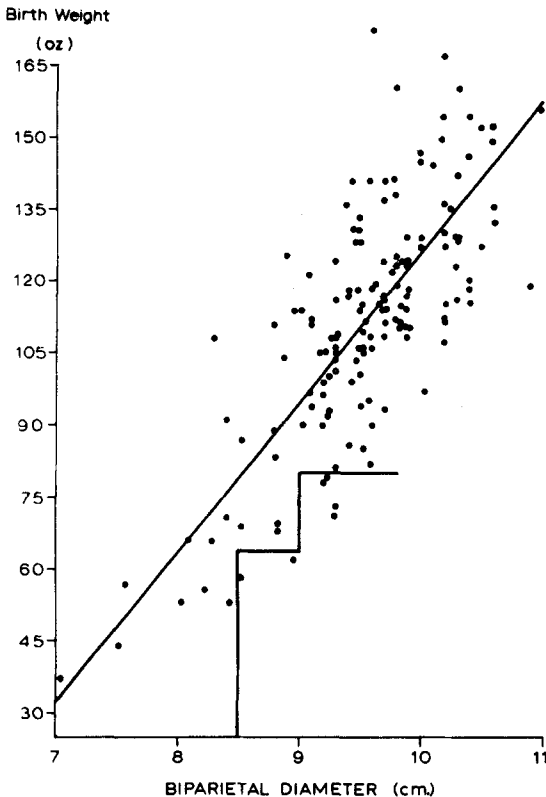


FIG. 4

Relationship between birth weight and foetal biparietal diameter measured by ultrasound 7 days or less before delivery.

Gestation

In spite of the high correlation (0.68) between gestation time and the size of the biparietal diameter, the measurement is not useful for the determination of foetal age since an estimate of gestation based on the value of the diameter has a standard error of approximately 25 days.

Growth of the Biparietal Diameter

The analysis of cases measured on four or more occasions indicates that in the last quarter of pregnancy the biparietal diameter increases linearly as the pregnancy progresses. In two of the 25 cases (see Table II) growth has faltered, one being a case of hypertension and the other a case of albuminuric pre-eclampsia; in the latter case, foetal death occurred during labour. For the remaining 23 cases the mean rate of growth was 0.023 cm./day, with a standard deviation of 0.006 cm./day. In various complications of pregnancy we want to know whether the growth of the foetus is impaired or not. There is at the moment no direct or reliable indirect indicator of foetal growth. Serial measurements of the biparietal diameter by ultrasound may provide such an index. The amount of data so far accumulated is insufficient to produce any norms, but the possibility seems well worth while investigating. For example, if the difference between two measurements separated by

a week is zero or negative (subtracting the earlier from the later observation) there is only a 20 per cent chance that the growth proceeds at the average rate quoted above; a similar conclusion is reached if the difference is 0.14 cm. or less for two measurements separated by two weeks. These values should be regarded as examples, since 0.13 cm. taken as the standard deviation of the measurements is probably too large for reasons given in the section dealing with the accuracy of the method.

Biparietal Growth and Maternal Characteristics

The longitudinal data fail to show any significant relationship between the rate of growth and maternal age, height or parity. For given gestation, the mean size of the biparietal diameter shows no differences according to maternal age or parity. Cases with measurements taken after 240 days of gestation were sorted into 5 ten-day groups to examine the correlation between maternal height and the absolute size of the diameter. All groups yielded positive correlation coefficients of similar magnitude. The average correlation estimated from this set was 0.25.

The Effects of Clinical Condition

Clinical groups distinguished in Table II were compared using the last available ultrasonic measurement of the foetal biparietal diameter. Differences due to the different timing of the measurements were allowed for by regression. The differences between the regression coefficients of the diameter on gestation (days) were small and insignificant. The group means were then adjusted to 265 days of gestation and tested for differences. The only significant difference found was that for the group of cases of albuminuric pre-eclampsia whose adjusted mean was 8.97 cm. as compared with 9.52 cm. for the uneventful pregnancies. In fact 5 out of the 10 cases in this group were well below the overall average for their gestation as illustrated in Figure 5.

A study of longitudinal cases suggests that in some cases growth becomes retarded so as to make it non-linear with respect to time as illustrated in Figure 6. It was not possible to say whether the onset of the condition coincided in time with the faltering of growth.

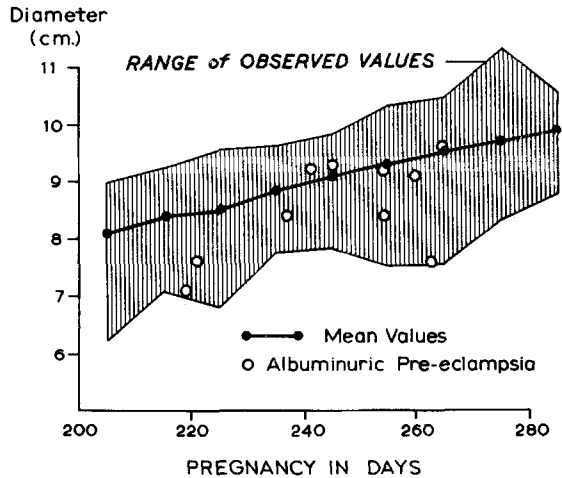


FIG. 5

Foetal biparietal diameter in albuminuric pre-eclampsia.

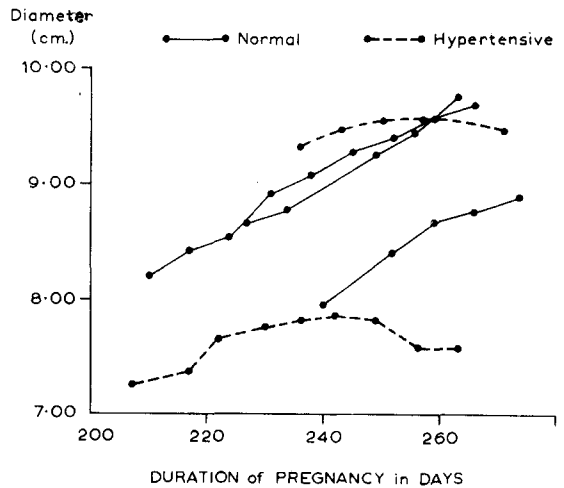


FIG. 6

Growth of biparietal diameter in normal and in hypertensive pregnancies.

CONCLUSION

The great advantage of cephalometry by ultrasonic echo sounding lies in the fact that the examination is simple, that the result is immediately available to the clinician and that it is safe for the patient and the baby (Donald *et al.*, 1958) and can be repeated as frequently as desired.

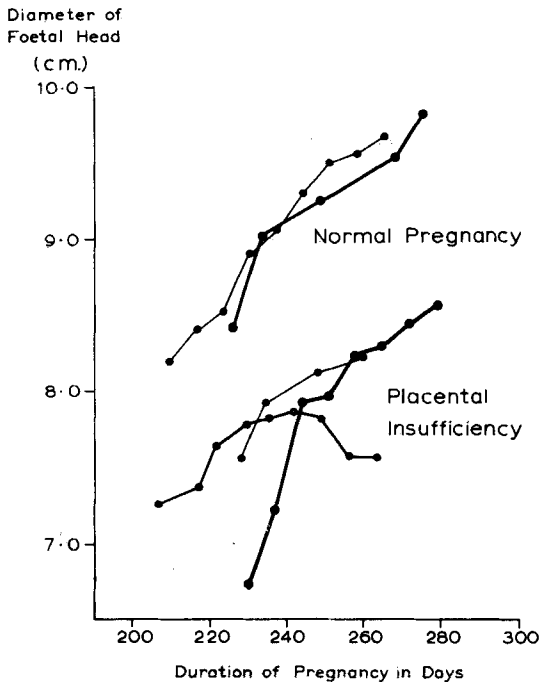


FIG. 7
Growth of foetal head.

The findings in individual cases have been of great interest and undoubted clinical value as has been shown in detail elsewhere (Willocks, 1963). This is illustrated by Figure 7 in which growth curves obtained in normal pregnancy are contrasted with those obtained in cases of presumed placental insufficiency from a variety of causes. The method can be usefully applied in clinical practice to determine presentation, to assess foetal size and to observe foetal growth by making repeated measurements after the 28th week of pregnancy.

SUMMARY

A method of measuring the biparietal diameter of the foetal head *in utero* by ultrasonic echo sounding has been developed and has had extensive practical trial.

An industrial ultrasonic flaw detector is used to direct a beam of pulsed ultrasound through the maternal abdomen and to detect echoes from reflecting objects in the path of the beam. Characteristic echoes from each side of the

foetal head can be identified and have simultaneous maximum amplitude when the beam of ultrasound is directed along the biparietal diameter. The time between the arrival of echoes from the near and far sides of the foetal head is measured and, as the result of experimental work, the biparietal diameter in centimetres can be calculated.

On the basis of the work done it is believed that the speed of ultrasound in the living brain of the newborn child is 1,525 metres per second, a figure which is in good agreement with other published work. After birth, alterations in the biparietal diameter have been observed in the first day of life, when a decrease is not uncommon: thereafter, the diameter does not change appreciably during the first week of life.

The method compares favourably with cephalometry by X-rays and can be used in a number of situations where X-ray cephalometry is impossible—where the head is high or there is a malpresentation. The examination is simple and safe and the result is immediately available to the clinician. The method is used to define presentation in doubtful cases, to assess foetal size and to observe foetal growth by making repeated measurements after the 28th week of pregnancy. Observations have indicated that the average rate of growth of the biparietal diameter in the last 10 weeks of pregnancy is 1.6 millimetres per week; that the absolute size of the diameter is correlated with maternal height and that growth appears to be depressed in cases of albuminuric pre-eclampsia.

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