J. Anat. (1983), **137**, 2, pp. 271–278
With 3 figures
Printed in Great Britain

The surface area and volume of the human fetus

C. MEBAN

Department of Anatomy, The Queen's University of Belfast, Medical Biology Centre, 97 Lisburn Road, Belfast BT9 7BL

(*Accepted* 26 *November* 1982)

INTRODUCTION

There have been many studies of human fetal growth (for reviews, see Usher & McLean, 1974; Birkbeck, 1976; Southgate, 1978). This growth has often been quantified using measurements of weight or linear dimensions of the body (e.g., crown–rump length, crown–heel length and head circumference). The surface areas of some older fetuses (gestational ages exceeding 28 weeks) and neonates have been estimated by Lissauer (1903); Bordier & Fabre (1903); Michel & Perret (1906); Careddu (1930) and Haycock, Schwartz & Wisotsky (1978). Seitz (1908) determined the volume of 13 macerated and 27 non-macerated fetuses (body lengths 22–53 cm; gestational ages and body weight unknown) by water displacement. He reported that the specific gravity of these fetuses ranged from 1·040 to 1·055. According to Boyd (1935), a Russian worker named Sytscheff (1902) measured the body volume of two aborted fetuses and one neonate; unfortunately, further details of the study are not available.

This paper presents estimates of the surface areas and volumes of 79 human fetuses.

MATERIALS AND METHODS

A total of 79 dead human fetuses (menstrual age, 11–42 weeks; body weight, 8–4080 g) was used in this study. Some of the older fetuses had been born alive and had breathed for varying periods of time (5 minutes to 6 hours); the remainder had either been stillborn or spontaneously aborted. The body weight, crown–rump length and crown–heel length of each fetus were consistent with its reported gestational age.

Body volume and surface area were computed using a modification of the procedure developed by Haycock *et al.* (1978). Essentially, the body was considered to be composed of a set of regular geometric solids. For example, the head was represented by a sphere and various parts of the limbs by cylinders. The volume and surface of each component was computed using measured values of its length and circumference (see Table 1). The crown–heel and crown–rump lengths were determined by use of a measuring board fitted with a fixed head plate and a movable base plate. All other straight line measurements were made with steel callipers. The larger circumferences were measured with a paediatric tape. Nylon thread was used to estimate the smaller circumferences. The thread was wrapped three times around the body part at the appropriate level and the overlapping ends were cut off. The length of the thread was then measured and divided by three to obtain the circumference.

The surface areas of 6 fetuses were also determined by two other methods:

(1) The body of the fetus was systematically covered with strips of aluminium foil

Table 1. *Measurements taken for estimation of body surface area and volume*

(Each part of the body was represented by one of the following geometric models: (A) surface of a sphere; (B) curved surface of a cylinder; (C) curved surface of a cylinder plus the cross sectional area of one end; (D) volume of a sphere; (E) volume of a cylinder)

Body part	Length	Circumference	Geometric model for area calculation	Geometric model for volume calculation
Head	—	Mean of occipitofrontal and occipitomental circumferences	Model A (minus the cross sectional area of the neck	Model D
Neck	Hyoid cartilage – interacromial line	Mean of minimum circumference and the circumference at the level of the tips of the acromial processes	Model B	Model E
Trunk	Intercromial line – intertrochanteric line	Mean of circumferences at levels of nipples, umbilicus and greater trochanters	Model B (minus the cross sectional areas of the upper arms)	Model E
Upper arm	Tip of acromion process – olecranon	Circumference at midpoint	Model B	Model E
Forearm and hand	Olecranon – distal end of 4th metacarpal bone	Mean of circumferences at midpoint and wrist	Model B	Model E
Fingers	Distal end of 2nd metacarpal bone – distal end of 2nd digit	Circumference at midpoint of middle phalanx	Model C (×5)	Model E (×5)
Thigh	Greater trochanter – head of fibula	Circumference at midpoint	Model B	Model E
Lower leg	Head of fibula – lateral malleolus	Mean of circumference at midpoint and the minimum circumference	Model B	Model E
Foot	Posterior border of heel – distal end of 3rd toe	Circumference at midpoint	Model C	Model E

(Alcan Polyfoil Ltd., Chesham, Bucks.; thickness 16·9 μm) and marks were made with a skin pencil to indicate the position of each strip. Most of the body was easily covered with foil strips of width 1–5 cm. However, irregularly shaped pieces were required to obtain a faithful mould of regions such as the ears, nose, digits and external genitalia. All the strips were weighed and the surface area was calculated, using the value 4·8 mg.cm^{-2} as the area/mass constant of the foil.

(2) The fetus was immersed in phosphate-buffered 10% formol saline for 18 hours. Its skin was dissected off and the pieces were pinned on to a sheet of cork, taking care not to stretch them. When the pieces of skin were dry, the areas were estimated by tracing their outlines on to graph paper.

In addition, the volumes of 6 fetuses were determined by a water displacement method. A plastic tank (fitted with an overflow pipe) was filled with water. The body orifices of the fetus were sealed with thin adhesive tape and a weight of known volume (V_1) was strapped to the lower abdominal wall. The fetus was then completely submerged in the water and the volume (V_2) of water displaced was measured. The volume of the fetal body was calculated as the difference in the volume of water displaced and the volume of the weight (i.e. $V_2 - V_1$).

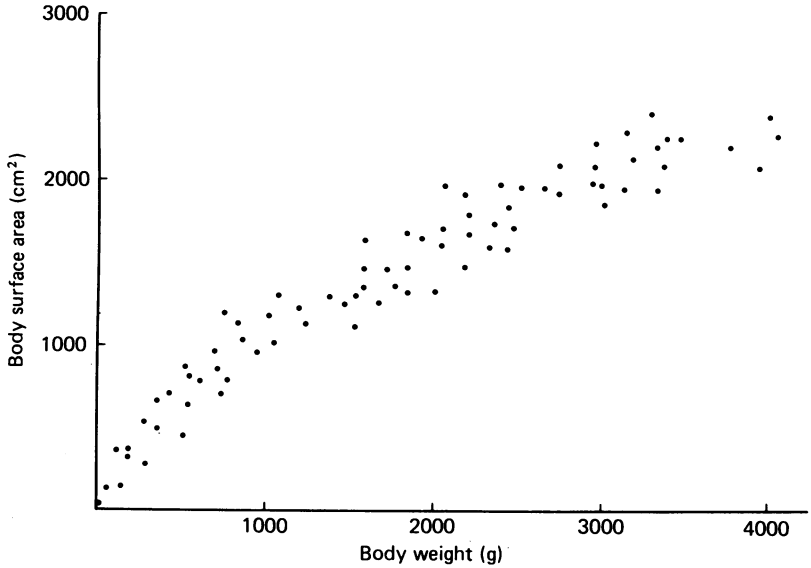

Fig. 1. Plot of fetal surface area against body weight.

RESULTS

The estimated surface area of the body was found to increase from about 30 cm² at 11 weeks of gestation to about 2200 cm² at full term (Fig. 1). An initial analysis of the estimates showed that the correlation of body surface area with any one parameter (e.g. body weight, crown–rump length, crown–heel length or gestational age) was relatively weak. The formula

$$S = 6{\cdot}4954 \times W^{0{\cdot}562} \times L^{0{\cdot}320}$$

was therefore derived from the data by multiple regression analysis. This provided a satisfactory expression of the relationship between surface area (S, in cm²) and two variables, body weight (W, in g) and crown–heel length (L, in cm), throughout the range 30–2400 cm² (correlation coefficient 0·979).

The youngest fetus (11 weeks, weight 8·0 g) in this series had a volume of 8·4 cm³, while the corresponding value for the oldest fetus (42 weeks, weight 4080 g) was 4175 cm³ (Fig. 2). Body volume (V, in cm³) was best defined by the bidimensional equation

$$V = 0{\cdot}6056 \times W^{0{\cdot}752} \times L^{0{\cdot}638}$$

where W is the weight in g and L the crown–heel length in cm (correlation coefficient 0·953).

The geometric method, the aluminium foil method and the skin dissection method all yielded similar estimates of surface area (Table 2). Furthermore, estimates of body volume based on the geometric method were in good agreement with the values obtained by direct measurement (Table 3).

DISCUSSION

Many methods have been used in the past to measure the surface area and volume of the human body. Sappey (1852) skinned a cadaver and pinned the pieces of skin to a table. When the pieces were dry, he placed them on a metric grid and deter-

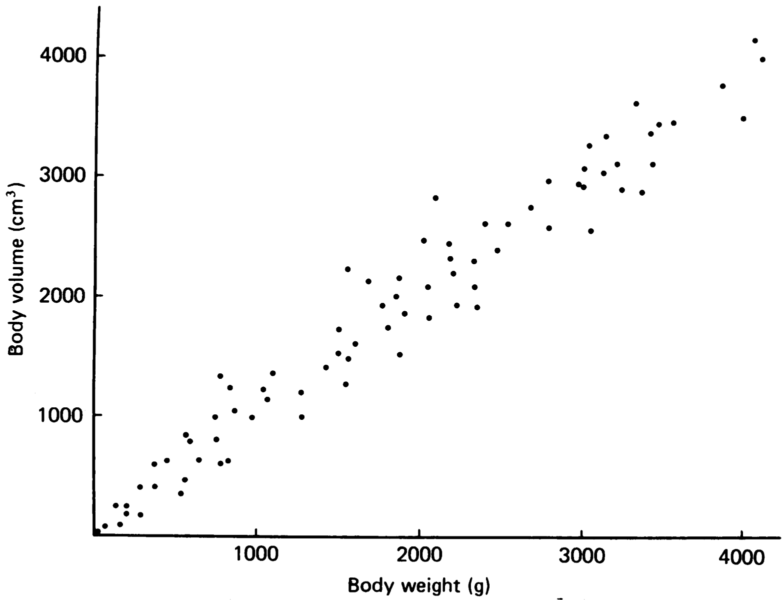

Fig. 2. Plot of fetal volume against body weight.

Table 2. *Estimates of body surface area obtained by three different methods*

Body weight of fetus (g)	Body surface area (cm²) Geometric method	Aluminium foil method	Skin dissection method
148	284	296 (+4·2%)*	273 (−3·9%)*
371	524	508 (−3·1%)	489 (−6·7%)
528	757	807 (+6·6%)	803 (+6·1%)
815	933	970 (+4·0%)	893 (4·3%)
1005	1127	1108 (−1·7%)	1177 (+4·4%)
2504	1882	1940 (+3·0%)	1929 (+2·5%)

* Difference between this value and that obtained using the geometric method expressed as a percentage.

Table 3. *Estimates of fetal body volume obtained by two different methods*

Body weight of fetus (g)	Geometric method	Water displacement method
148	141	151 (+6 6%)*
371	416	380 (−8·6%)
528	505	536 (+6·1%)
815	843	820 (−2·7%)
1005	1049	1015 (−3·2%)
2504	2432	2537 (+4·3%)

* Difference between this value and that obtained using the geometric method expressed as a percentage.

mined their area. Some workers covered cadavers or live subjects with inelastic materials which were later removed and measured (Funke, 1858, Meeh, 1879; Gött & Schmidt, 1912; Dubois & Dubois, 1914, Wörmer, 1923; Takahira & Kitagawa, 1924; Boyd, Scammon & Lawrence, 1930). Other investigators marked out regular geometric figures on the skin and then calculated the areas of the figures from their linear dimensions (Fubini & Ronchi, 1881; Bouchard, 1897; Lassablière, 1924). Roussy (1899) and Bordier (1901), using planimeters, measured the surface area of adults. The density and volume of children and adults were determined by the use of the Archimedean weighing principle (Boyd, 1933), or a body pletysmograph (Kleiber, 1961). More recently, Whittle, Herron & Cuzzi (1976) produced a detailed mathematical description of the three dimensional form of the human body, and they used this to compute the volumes and surface areas of the crewmen on the Skylab Space Missions. The Cartesian co-ordinates of selected points on the surface of each crewman were determined from stereogrammetric photographs taken before and after flight.

In the present study, body volume and surface area were estimated by the use of a geometric procedure. This method has some obvious advantages: the dimensions of the body parts can be measured relatively quickly; no special equipment is required; the body of the subject is not disfigured; and the resulting data can readily be processed by computer. The surface area and volume were determined by other methods in order to check the validity of this approach. In each case, the estimates based on the geometric procedure were in fairly close agreement with the values obtained using the independent methods.

The most satisfactory expression of the increase in body surface area during fetal life is provided by the equation

$$S = 6{\cdot}4954 \times W^{0{\cdot}562} \times L^{0{\cdot}320}$$

where S is the surface area in cm^2, W is the body weight in g, and L is the crown–heel length in cm. A bifactorial expression of this type gives a better fit for the computed areal values than formulae based on only one variable. Estimates of body surface area are now used to calculate several different types of physiological data (e.g. basal metabolic rate, renal clearance rate, radiant heat exchange, and the transcutaneous fluid loss: see McCrory, 1972; Brobeck & Dubois, 1980; Hardy, 1980). In addition, the dosages of many of the drugs used in paediatric practice are calculated on the basis of surface area (Shirkey, 1980; Silver, Peterson & Rumack, 1980). A nomogram (Fig. 3) has been constructed, using values derived from the surface area – weight – length equation described above. Other investigators may wish to use this nomogram to obtain estimates of the body surface area of fetuses or pre-term babies.

The data collected in the present study indicate that the human body undergoes a 400-fold increase in volume during the fetal period. At first sight it might be expected that the volume of a fetus should be directly proportional to the third power of a linear dimension of its body. However, it was found that body volume was not completely dependent on crown–heel length. As in the case of surface area, the volumetric increase was best described by an equation that included both body weight and crown–heel length. A fetus not only increases in size, but also undergoes significant changes in shape, during its development. Consequently, its volume (V) cannot be accurately defined by a simple equation of the type $V = kL^n$, where k is a constant, L is a linear body dimension and n is an exponent ($\doteq 3$).

The density of each fetus has been calculated, using its body volume and weight

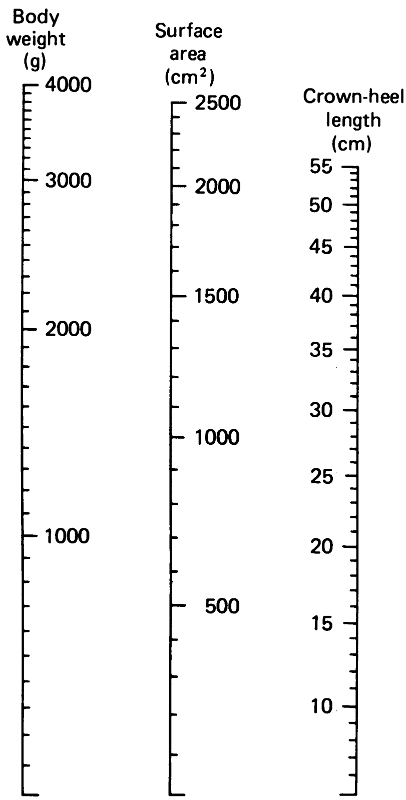

Fig. 3. Nomogram for estimating the body surface area of human fetuses and neonates. It is based on the equation $S = 6{\cdot}4954 \times W^{0{\cdot}562} \times L^{0{\cdot}320}$ where S is the surface area in cm^2, W is the body weight in g, and L is the crown–heel length in cm. To use the nomogram, a ruler is aligned with the length and weight values on the outer axes. The point at which the central axis is intersected gives the value for body surface area.

Table 4. *Body densities of human fetuses*

Body weight (g)	Mean density ($g/cm^{-3} \pm$ S.E.)
< 1000	$0{\cdot}971 \pm 0{\cdot}092$
1000 —	$0{\cdot}988 \pm 0{\cdot}031$
2000 —	$0{\cdot}999 \pm 0{\cdot}018$
> 3000	$1{\cdot}021 \pm 0{\cdot}020$

values. The differences between the mean densities of the fetuses in the various weight groups are not statistically significant (Table 4). The value obtained for the older fetuses in this study (weight > 3000 g, mean density 1·021 $g.cm^3$) is of comparable magnitude to those measured in neonates by total body plethysmography (mean density of males 1·026 $g.cm^{-3}$ and mean density of females 1·022 $g.cm^{-3}$; Yssing & Friis-Hansen, 1965).

Like all small mammals, the human fetus has a relatively large surface area. For example, an adult man (weight 70 kg, height 170 cm) has a surface area (cm^2)/volume (cm^3) ratio of about 0·26 while the corresponding ratios for fetuses of body weight 3250 g and 500 g are 0·65 and 1·30, respectively. A neonate, particularly one born prematurely, is obviously at a disadvantage in having a high surface area/volume ratio. It can rapidly lose heat to (or gain heat from) the environment and, consequently, its body temperature tends to be less stable than that of an adult.

SUMMARY

The surface area and volume of 79 human fetuses (body weight 8–4080 g) were estimated by use of a geometric method. It was found that body surface area increased by a factor of about 70, and body volume by a factor of about 400, during the fetal period. Surface area (S, in cm^2) was related to body weight (W, in g) and crown–heel length (L, in cm) according to the equation

$$S = 6{\cdot}4954 \times W^{0{\cdot}562} \times L^{0{\cdot}320}$$

while volume (V, in cm^3) was related to the same two variables by the equation

$$V = 0{\cdot}6065 \times W^{0{\cdot}752} \times L^{0{\cdot}638}.$$

The former equation was used to construct a nomogram for estimating the surface area of human fetuses and neonates.

I wish to thank the following for their assistance with different aspects of this study: Miss R. Burton, Dr P. J. Connelly, Miss E. Graham, Dr J. Hill, Mr E. Murray, Dr D. O'Hara, Dr C. Patterson, Miss J. M. Smith and Mr J. White.

REFERENCES

BIRKBECK, J. A. (1976). Metrical growth and skeletal development of the human fetus. In *The Biology of Human Fetal Growth* (ed. D. F. Roberts & A. M. Thomson), pp. 39–68. London: Taylor & Francis.

BORDIER, H. (1901). Sur la mesure de la surface du corps de l'homme. Appareil permettant d'effectuer cette mesure (Intégrateur de surfaces). *Journal de physiologie et de pathologie générale* **3**, 673–680.

BORDIER, H. & FABRE, G. (1903). Valeur de la surface spécifique chez les enfants nouveau-nes. *Bulletin de la Société d'obstétrique et de gynécologie de Paris* **6**, 212–214.

BOUCHARD, C. (1897). Détermination de la surface, de la corpulence et de la composition chimique du corps de l'homme. *Comptes rendus de l'Académie des sciences* **124**, 844–851.

BOYD, E. (1933). Specific gravity of the human body. *Human Biology* **5**, 646–672.

BOYD, E. (1935). *The Growth of the Surface Area of the Human Body*. Minneapolis: University of Minnesota Press.

BOYD, E., SCAMMON, R. E. & LAWRENCE, D. (1930). The determination of surface area of living children. *Proceedings of the Society for Experimental Biology and Medicine* **27**, 445–449.

BROBECK, J. R. & DUBOIS, A. B. (1980). Energy exchange. In *Medical Physiology* (ed. V. B. Mountcastle), 14th ed., pp. 1351–1461. St. Louis: The C. V. Mosby Co.

CAREDDU, G. (1930). Studi su bambini normali ed ipotrofici nel primo biennio di vita in rapporto con lo sviluppo della superficie corporea direttamente misurata. Nota II. Metabolismo basale. *Rivista di Clinica Pediatrica* **28**, 553–573.

DUBOIS, D. & DUBOIS, E. F. (1914). The measurement of the surface area of adults. *Proceedings of the Society for Experimental Biology and Medicine* **12**, 16–18.

DUBOIS, D. & DUBOIS, E. F. (1915). The measurement of the surface area of man. *Archives of Internal Medicine* **15**, 868–881.

FUBINI, S. & RONCHI, J. (1881). Ueber die Perspiration der Kohlensäure beim Menschen. *Untersuchungen zur Naturlehre des Menschen und der Thiere* **12**, 1–30.

FUNKE, O. (1858). Beiträge zur Kenntniss der Schweissecretion. *Untersuchungen zur Naturlehre des Menschen und der Thiere* **4**, 36–57.

GÖTT, T. & SCHMIDT, H. (1912). Beitrage zur Frage der frühinfantilen Amyotrophien und einer sie begleitenden 'endogenen' Fettsucht. *Zeitschrift für Kinderheilkunde* **3**, 256–285.

HARDY, J. D. (1980). Body temperature regulation. In *Medical Physiology* (ed. V. B. Mountcastle), 14th ed., pp. 1417–1456. St. Louis: The C. V. Mosby Co.

HAYCOCK, G. B., SCHWARTZ, G. J. & WISOTSKY, D. H. (1978). Geometric method for measuring body surface area: a height-weight formula validated in infants, children, and adults. *Journal of Pediatrics* **93**, 62–66.

KLEIBER, M. (1961). *The Fire of Life*. New York: John Wiley & Sons.

LASSABLIÈRE, P. (1924). La mesure de la surface du corps de l'enfant. *La Médecine* **5**, 934–935.

LISSAUER, W. (1903). Ueber Oberflächenmessungen an Säuglingen und ihre Bedeutung für den Nahrungsbedarf. *Jahrbuch für Kinderheilkunde* **58**, 392–411.

MCCRORY, W. W. (1972). *Developmental Nephrology*. Cambridge, Mass.: Harvard University Press.

MEEH, K. (1879). Oberflächenmessungen des menschlichen Körpers. *Zeitschrift für Biologie* **15**, 425–458.

MICHEL, C. H. & PERRET, M. (1906). La ration alimentaire de l'enfant depuis sa naissance jusqu'à l'âge de deux ans. *Revue de la Société scientifique d'hygiène alimentaire* **3**, 209–362.

ROUSSY, B. (1899). Nouvelle méthode de mensuration directe de la surface de la peau humaine, etc., au moyen d'un nouvel appareil: le Pelliplanimètre à compteur totalisateur et à surface variable (Pelliplanimètre). *Comptes rendus de la Société de biologie* **51**, 375–377.

SAPPEY, P. C. (1852). *Traité d'Anatomie Descriptive*. Paris: Maretheux.

SEITZ, L. (1908). Ueber den Einfluss der Schwerkraft auf die Entstehung der Schädellagen. *Archiv für Gynàekologie* **86**, 114–144.

SHIRKEY, H. C. (1980). Table of drugs. In *Pediatric Therapy* (ed. H. C. Shirkey), 6th ed., pp. 1143–1229. St. Louis: The C. V. Mosby Co.

SILVER, H. K., PETERSON, R. G. & RUMACK, B. H. (1980). Drug therapy. In *Current Pediatric Diagnosis & Treatment* (ed. C. H. Kempe, H. K. Silver & D. O'Brien), pp. 1029–1047. Los Altos, California: Lange Medical Publications.

SOUTHGATE, D. A. T. (1978). Fetal measurements. In *Human Growth*. 1. *Principles and Perinatal Growth* (ed. F. Falkner & J. M. Tanner), pp. 379–395. London: Baillière Tindall.

SYTSCHEFF, A. I. (1902). Izmerenie obyoma i poverkhosti tel u detei po vozrastam. Dissertation, St. Petersbury. Cited by Boyd (1935).

TAKAHIRA, H. & KITAGAWA, S. (1924). On the measurement of surface area of the Japanese and a formula to express it. *Bulletin of the Imperial Government Institute for Nutrition, Tokyo* **6**, 125–127.

USHER, R. H. & MCLEAN, F. H. (1974). Normal fetal growth and the significance of fetal growth retardation. In *Scientific Foundations of Paediatrics* (ed. J. A. Davis & Dobbing), pp. 69–80. Philadelphia: W. B. Saundsrs Co.

WHITTLE, M. W., HERRON, R. E. & CUZZI, J. R. (1976). Biostereometric analysis of body form: the second manned Skylab mission. *Aviation, Space and Environmental Medicine* **47**, 410–412.

WÖRNER, H. (1923). Die Oberfläche des menschlichen Körpers. *Zeitschrift für die gesamte experimentelle Medizin* **33**, 510–526.

YSSING, B. & FRIIS-HANSEN, B. (1965). Body composition of newborn infants. *Acta paediatrica Suppl.* **159**, 117–118.