mens were made on several grafts to confirm the observation made at the site of the graft.

It is apparent from the data (Table 1) that irradiation did not affect the fate of the co-twin grafts ($P = .6$). However, the salient point of the data is that 56.1 percent (23/41) of the twins rejected their co-twin grafts. In contrast, the homografts were rejected within 15 days, and the autografts were accepted indefinitely. Thus, chimeric twins may not be fully tolerant to each other's skin even though they are tolerant to each other's hematopoietic tissues and thereby sustain erythrocyte chimerism. This situation may be another example of "split tolerance" (*9*) which has been observed among animals made tolerant artificially. Among the 41 twins in the experiment, there were seven whose twins were not studied because of their death or mechanical loss of their grafts. There was considerable variation in the reactions of partners among the 17 remaining pairs. Neither partner of two pairs of twins rejected its twin's grafts during the 200-day period of observation. In contrast, both partners of four pairs of twins rejected their co-twin grafts. Finally, asymmetric responses were observed among 11 pairs; that is, only one member of a pair rejected its twin's graft. There was no apparent correlation between the degree of tolerance exhibited and the asymmetry of the chimeric red-cell populations (*10*).

The time at which complete rejection of the co-twin grafts occurred ranged from 122 to 468 days, and it was not affected by irradiation. The reactions were unlike the acute and decisive homograft rejections observed within 15 days after grafting, but were mild and chronic, lasting from 1 to 3 months. In addition to histologic examination of biopsy tissues, second-set reactions confirmed that the rejections were the result of histocompatibility differences (Table 2). On the average, the second co-twin grafts were rejected in about half the time (121 days) required for the rejection of first grafts (229 days). Twins which failed to reject their first grafts also failed to reject their second grafts.

These data show that varying degrees of tolerance may be established between chimeric twins with respect to histocompatibility antigens. As suggested by Billingham and Lampkin (*3*), this may be due to antigenic differences between the twins and to differences with which the immunologically responsive tissues in each twin became invaded or permeated with cells from its twin.

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References and Notes

1. D. Anderson, R. E. Billingham, G. H. Lampkin, P. B. Medewar, *Heredity* **5**, 379 (1951).
2. R. D. Owen, *Science* **102**, 400 (1945).
3. R. E. Billingham and G. H. Lampkin, *J. Embryol. Exp. Morphol.* **5**, 351 (1957).
4. W. H. Stone, C. Stormont, M. R. Irwin, *J. Animal Sci.* **11**, 744 (1952).
5. W. H. Stone and R. G. Cragle, *Science* **146**, 430 (1964).
6. W. H. Stone and R. D. Owen, *Transplantation* **1**, 107 (1963).
7. J. Rendel, *Z. Tierzücht. Züchtungsbiol.* **79**, 75 (1963).
8. A. P. Menge and W. H. Stone, *Proc. Soc. Expt. Biol. Med.* **102**, 107 (1959).
9. O. Stark, V. Kren, B. Frenzl, R. Brdicka, in *Mechanisms of Immunological Tolerance*, M. Hašek, A. Lengerova, M. Vojtiskova, Eds. (Czechoslovak Academy of Sciences, Prague, 1962), p. 123.
10. W. H. Stone, J. Friedman, A. Fregin, *Proc. Nat. Acad. Sci. U.S.* **51**, 1036 (1964).
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Potassium-40 Content as a Basis for the Calculation of Body Cell Mass in Man

Abstract. *On the assumption that the potassium content of the body cell mass is constant it should be possible to estimate body cell mass by measuring potassium-40 activity with a whole-body scintillation counter. Relations of body cell mass to weight, lean body mass, and total body water are demonstrated.*

It was suggested by Forbes *et al.* (*1*) and Anderson and Langham (*2*) that lean body mass might be calculated with the aid of the total potassium content of the body (K). These authors determined K (in milliequivalents) by means of a whole-body radiation counter and divided this value by 68.1 (*1*) or 63 (*2*), respectively, thus obtaining lean body mass in kilograms.

Forbes *et al.* (*1*) have already pointed out that lean body mass in infants and small children cannot be determined in this way, since the potassium content in newborn infants is only 48 meq/kg of lean body mass. Obviously, the change of the content of K in lean body mass during growth is due to a shifting in the relation between intracellular fluid and extracellular fluid, the first of which contains a high concentration of potassium, while the concentration of potassium in the latter is low. It is generally accepted that the relation between intra- and extracellular fluid with growing body size is altered in favor of the intracellular fluid.

Since more than 95 percent of the potassium is contained in the intracellular fluid, it is useful to compare the increase in the amount of the fluid or the growth of body cellular mass (CM), which consists of up to 67 percent of intracellular fluid, with the increase in K. By determining the extracellular fluid in infants and children, and from total body water values I developed the following equation (*3*).

$$CM = 0.42 \times W^{1.11} \qquad (1a)$$

where W represents weight in kilograms. This equation is in good agreement with another developed by Friis-Hansen (*4*), who also found a regression of $W^{1.09}$ for intracellular fluid.

For the calculation of K I made use of 4300 measurements taken by Oberhausen and Onstead (*5*). The data were collected from subjects aged between 6 and 20 years by means of the whole-body radiation counter in Landstuhl (Germany). By correlation of the median values the following equation was obtained for male persons.

$$K = 39.2 \times W^{1.09} \qquad (2)$$

Equation 2 is applicable not only in the range of the measured values but holds true even for fetuses weighing 350 g, as can be seen by a comparison of the values obtained by Iob and Swanson (*7*).

It may be seen from Eqs. 1 and 2 that, during growth, CM and K have an equal relation to W. If a quotient is derived from Eqs. 1 and 2, the result will be the biological K-equivalent (K_{CM}) for 1 kg of cell mass. For man this equivalent is 92.5

meq/kg. Analogous to the lean body mass relations found by Forbes and Anderson, is the resulting equation

$$CM = \frac{K}{92.5} = 0.0108 \times K \qquad (3)$$

In its basic form of

$$CM = \frac{K}{K_{CM}} \qquad (3a)$$

this equation is also applicable for certain animals, since a relation comparable to Eq. 2 is found also for rats, rabbits, and pigs (*7*). Furthermore, it can be inferred from Eqs. 1 and 2 that the intracellular potassium concentration will be 138 meq/lit. of fluid, the extracellular proportion of potassium being neglected. Since the organs and muscular tissue grow at a different rate (as can be deduced from the different allometric functions), the variation of tissue proportions in *CM* does not influence the total intracellular potassium concentration. Thus, it must be concluded that potassium concentration will not only remain constant during growth, but also that it is equal in all cells.

To establish the relation between *CM* and lean body mass, it must be considered that lean body mass consists of *CM*, extracellular fluid, and extracellular solids (S_e). The extracellular fluid (*ECF*) can be calculated from the body surface area (*SA*):

$$ECF = 6.04 \times SA \qquad (4)$$

(*SA* being calculated according to the equation of Dubois and Dubois (*8*) in square meters). This function was developed with the determination of the thiosulfate space (*3*). It is as valid with adipose as with dystrophic persons.

The relation of extracellular solids and *CM* should be a linear one, as the composition of *W* minus *ECF* is a rather constant one during growth (*3*). The corresponding relation

$$S_e = 0.1 \times CM \qquad (5)$$

is only assessed. A deviation up to 0.04 *CM* is possible. The resulting function for lean body mass (*LBM*) is

$$LBM = 1.1\ CM + ECF = 0.0119\ K + 6.04\ SA \qquad (6)$$

The lean body mass of a male adult (weight, 68.9 kg; height, 172.7 cm; *K*, 3870 meq) will thus be 57.0 kg and the lean body mass of a newborn infant (weight, 3.0 kg; length, 49 cm; *K* calculated from Eq. 2, 130 meq) is 2.7 kg. These *K*/*LBM* quotients correspond very well to those of Forbes *et al.* (*1*). I found 67.9 meq/kg compared with 68.1 meq/kg (*1*); for newborn infants my value is 48.1 meq/kg, while that of Forbes *et al.* (*1*) is 48.0 meq/kg.

The total body water (*TBW*) is calculated according to the function:

$$TBW = 0.67\ CM + ECF = 0.0072\ K + 6.04\ SA \qquad (7)$$

The total body water for the examples given would thus be 38.8 and 2.09 liters, respectively, and consequently the water content of lean body mass would be 68.1 and 77.4 percent.

Finally, *CM* must be examined as a basis for allometric functions. Although Eq. 1 is an allometric function biologically, it does not appear to be very reasonable, because, during growth, weight (*W*) develops as a function of *CM* and not vice versa. Thus the equation should read:

$$W = 2.16 \times CM^{0.00} \qquad (1b)$$

If, however, weight is a function of *CM*, all allometric functions should be based on *CM*. The original form of the allometric function is transformed from

$$Y = a \times W^b \qquad (8)$$

to read

$$Y = a_1 \times CM^{b_1} \qquad (8a)$$

where *Y* is the relative growth of the body size; *a* and *b* can be transformed into a_1 and b_1 by a simple calculation process, as was demonstrated by Adolph (*9*). Differentiated by time and divided by itself, Eq. 8a will read

$$\frac{dy}{dt} \times \frac{1}{y} = b_1 \times \frac{dCM}{dt} \times \frac{1}{CM} \qquad (8b)$$

That is, an allometric function is given, if the relative growth of the body size examined has a linear relation to the relative growth of *CM*.

Allometric organ functions do not offer a basis which would be very advantageous for the assessment of the capacity of these organs (for example, renal function is related to body surface area since the weight of the kidneys is proportional to $W^{0.7}$). During growth the amount of cellular mass in the organs may change considerably. It is much more advantageous to calculate the *CM* proportion CM_{org} present in an organ from its potassium content, K_{org}, according to

$$\frac{K_{org}}{K_{CM}} = CM_{org} \qquad (9)$$

since the cells contained in an organ are doing the work of the organ. The corresponding allometric function would thus read

$$CM_{org} = a \times CM^b \qquad (10)$$

Finally, it should be noted that cell mass provides a good reference standard for the total energy conversion, for renal functions, and elimination of creatinine.

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References and Notes

1. G. B. Forbes, I. Gallup, J. B. Hursch, *Science* **133**, 101 (1961).
2. E. C. Anderson and W. H. Langham, *ibid.* **130**, 713 (1959).
3. W. Burmeister, *Ann. Univ. Saraviensis Med.* **9**, 167 (1961/62).
4. B. Friis-Hansen, *Pediatrics* **28**, 169 (1961).
5. E. Oberhausen and L. O. Onstead, 2nd Symposium on Radioactivity in Man at Northwestern Univ. Medical School, Chicago, 1962, in press; W. Burmeister, *Ann. Paediat. Basel*, in press.
6. V. Iob and W. W. Swanson, *Am. J. Diseases Children* **47**, 302 (1934).
7. G. B. Forbes, *Growth* **19**, 75 (1955).
8. D. Dubois and E. F. Dubois, *Arch. Internal Med.* **17**, 863 (1916).
9. E. F. Adolph, *Science* **109**, 579 (1949).
10. I thank Drs. E. Oberhausen and L. O. Onstead for permission to use the measurements taken with the whole-body radiation counter.

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Smooth Muscle: An Ultrastructural Basis for the Dynamics of Its Contraction

Abstract. *Electron micrographs of vertebrate and invertebrate smooth muscle indicate that the myofilaments are oriented obliquely to the long axis of the muscle fibers containing them and insert along the sides of the fibers. As a result, a greater proportion of the contractile elements are in parallel with one another and a smaller proportion are in series than would be possible if the myofilaments were strictly parallel to the fiber axis. From this ultrastructural organization it is possible to predict several well-known, but previously unexplained, physiological properties of smooth muscle.*

Smooth muscle is distinguished from striated muscle not only by its histological appearance but also by its physiological properties, notably its ability to sustain forceful contractions for prolonged periods with a minimum expenditure of energy and its relatively low velocity of shortening (*1*). Ultra-