Reports

Estimation of Total Body Fat from Potassium-40 Content

Abstract. A brief review is given of the development of methods for the determination of total body potassium by whole-body scintillation counting and of studies to establish the utility of body potassium as a measure of gross body composition including fat.

In a paper of the above title (*1*), it is stated that "a new approach to the estimation of fat content in living man" is presented, "namely, the use of whole-body potassium content as an index of lean body mass." The potassium is determined by measurement of the gamma-ray emission of potassium-40. Far from being new, this method can be traced back to 1951 and has been under study by the Biomedical Research Group of the Los Alamos Scientific Laboratory since 1953. (The following literature review covers only the determination of body composition by counting natural gamma radiation. The very important complementary studies of exchangeable potassium are not included.)

Historically, the first determinations of body potassium by means of its natural radioactivity were reported by Sievert (*2*) and by Burch and Spiers (*3*). Although this early work was directed primarily toward the determination of small additional amounts of other gamma-emitting nuclides (principally radium and thorium), Sievert (*2, 4*) established the change of the potassium content of the body with age and indicated the explanation in terms of body composition.

The measurement of potassium by whole-body scintillation counting of potassium-40 was first reported in 1953 by Reines *et al.* (*5*), who used a 4π liquid-scintillation counter, and in 1956 by Miller and Marinelli (*6*), who used a sodium-iodide crystal. Similar measurements were published later by McNeill and Green (*7*). The correlation between total body potassium and body water was demonstrated by Woodward *et al.* (*8*) in a paper in which the relation between potassium, lean body weight, and fat was discussed. In particular, the use of simultaneous water and potassium determinations to detect deviations from the normal was proposed. Such a procedure will undoubtedly be necessary for high precision work, since the body is not a simple two-component system.

Clarification of the details of the relationship between potassium and body composition has been a continuing major research program of the Biomedical Research Group since our 1953 measurements. In 1957, the correlation between potassium and lean body mass (as deduced from body water) was reported to be reliable to a standard deviation of 6 percent (*9*). As a more specific proof of the correlation, additional experiments were performed on other species so that verification by dissection and chemical analysis would be possible. Published reports include papers by Kulwich *et al.* on hams (*10*), by Zobrisky *et al.* on live pigs (*11*), and by Anderson on comminuted products (*12*).

Work on human subjects was extended with the report in 1959 (*13*) of measurements on 1590 persons with particular reference to variation of potassium with age and sex and the explanation in terms of fat and lean body weights. Detailed quantitative data were published by Allen *et al.* (*14*) comparing lean body weights calculated from potassium, water, and body density (determined by underwater weighing). The agreement between the various methods was shown to be excellent (standard deviation of 5 percent). The poor correlation reported by Forbes *et al.* (*1*) between potassium and skinfold thickness and height-to-weight ratios suggests that the latter two parameters provide poor estimates of body fat. In view of the long published history of research directed toward the determination of fat and of lean body mass from potassium as measured by whole-body gamma counting, it hardly seems that their statement of a "new approach" is justified.

In addition to this brief review of the historical development of the whole-body counting method, we wish to comment on the assumption by Forbes *et al.* (*1*) of a linear relation between water, potassium, and lean body weight. Our 1956 paper (*8*) used the 72 percent ratio of water to lean body weight, with the result that K (meq)/LBW = 63 meq/kg, compared with Forbes's value of 68. In a latter paper (*9*), we have shown that a better fit between water and potassium is obtained if allowance is made for the fact that fat tissue contains about 20 percent water (see *15*). [Allowing 31 percent water in fat tissue (*16*) apparently results in an over-correction.] The result, on this basis, was that K/LBW = 73 meq/kg, 8 percent higher than Forbes's ratio.

A basic difficulty in this sort of analysis is the well-known problem of defining "lean body mass" with precision. For this reason, we have preferred in our later work (*14*) to base the analysis of body composition on chemically defined components as suggested by Allen (*17*).

ERNEST C. ANDERSON
WRIGHT H. LANGHAM

Biomedical Research Group, Los Alamos Scientific Laboratory, University of California, Los Alamos, New Mexico

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3 February 1961

Instructions for preparing reports. Begin the report with an abstract of from 45 to 55 words. The abstract should *not* repeat phrases employed in the title. It should work with the title to give the reader a summary of the results presented in the report proper.

Type manuscripts double-spaced and submit one ribbon copy and one carbon copy.

Limit the report proper to the equivalent of 1200 words. This space includes that occupied by illustrative material as well as by the references and notes.

Limit illustrative material to *one* 2-column figure (that is, a figure whose width equals two columns of text) or to *one* 2-column table or to *two* 1-column illustrations, which may consist of two figures or two tables or one of each.

For further details see "Suggestions to contributors" [*Science* **125**, 16 (1957)].

The report by Anderson and Langham begins with an excellent historical survey of whole-body counter methodology. No one can deny the importance of the contribution which they and their co-workers have made in this field. As a result of their studies there are now available more data on the potassium content of man than for any other body constituent. But such a detailed exposé was clearly beyond the scope of our brief report in *Science* (*1*), nor is it germane to the substance of that report.

We considered the *technique* of potassium measurement to have been clearly established. Our intent was to develop an *application* of that technique, and this is what we did.

Apparently Anderson and Langham are not content with the references which we made (references 5, 6, 10) to their work (*2*). We have searched the writings of the Los Alamos group without finding more than oblique and vague references to fat determination in man by this technique. Mention is made (which we quoted) of lean body mass, and much emphasis is placed on the concept of bone mineral-free, water-free, and fat-free solids. It is surprising indeed that they could have been working on a method for fat determination since 1953 without once having published a value for actual fat content for any of their subjects. There was nothing to hinder them from doing so, and one can only conclude that they were not particularly interested in this aspect of body composition. Indeed, we ourselves have made such calculations from their data, which they have so generously made available to us, often in advance of publication.

In all fairness to history, it should be stated that the concept of the constancy of adult tissue composition when calculated on a fat-free basis long antedated the establishment of the Los Alamos group (*3*). In recent years a number of workers have applied this general principle to fat determination in living man by the total body water and densitometric techniques. Our intent was merely to suggest an extension of this principle to include potassium.

Our interest in this problem dates from some analyses of human carcasses made in 1954 and published in 1956 (*4*). Upon completion of the Rochester whole-body counter, measurements were made in 1959 and first reported at the May 1960 meetings of the American Pediatric Society. The calculations are based, not upon indirect estimates of fat content, but upon actual chemical analyses, and despite the protestations of Anderson and Langham, our work is the first to be published in which emphasis is placed on the estimation of fat content by means of the potassium technique in living man.

We are quite aware of the importance of the issue raised in the next to the last paragraph of their report. The question of the composition of the "lean body mass" in living man is one that can be approached only by indirect and inferential means, and inevitably involves assumptions based on the many animal and the all too few human analyses which have been done. As Anderson and Langham have indicated [and the recent data of Talso *et al.* (*5*) would bear them out], the potassium content of lean body mass calculated from simultaneous water measurement differs by a few percent from that derived from chemical analysis of carcasses. It is impossible to decide whether this discrepancy is due to a systematic error in the total body water method, or to the possibility that the analyzed specimens were not representative of the normal state.

At any rate, we were encouraged to proceed with our work by the report from the Los Alamos group—and we quote from our report (*1*)—of "a good correspondence between K^{40} content and lean body mass as determined by tritium dilution in man."

GILBERT B. FORBES
JOHN B. HURSH
School of Medicine and Dentistry, University of Rochester, Rochester, New York

References and Notes

1. G. B. Forbes, J. Gallup, J. B. Hursh, *Science* **133**, 101 (1961).
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Sound Production in Scorpions

The fact that some species of scorpions produce sound has been known for a long time. It was suggested by Landois and Wood-Mason in 1877 (from Werner, *1*) and recorded for the first time by Pocock (from Alexander, *2*). Several observations on the behavior of scorpions, morphological studies, and attempts to draw sound from preserved specimens led to the suggestion that various body parts might be involved in sound production by scorpions (summarized by Werner, *1*).

The subject was investigated in detail only recently, by Alexander (*2*), in *Opisthophthalamus latimanus* Koch., *O. nitidiceps* Poc. (Scorpionidae), and *Parabuthus planicauda* Poc. (Buthidae). The two species of the genus *Opisthophthalamus* were found to produce a hissing sound by rubbing the chelicerae against the ventral side of the carapace; whereas *Parabuthus planicauda* produced a shrill grating sound by scraping the tip of the tail across the first caudal tergite and the last mesosomal one. Vachon *et al.* (*3*) registered in 1958 the specters and oscillograms of the sound produced by *Opisthophthalamus latimanus*.

So far all mechanisms of sound production in scorpions, either suggested or actually investigated, have been based on stridulation—that is, friction between two body parts which may, or may not, bear special adaptations for sound production.

During studies on *Scorpio maurus* L. (Scorpionidae), we found that this scorpion produces sound by a mechanism which is basically different from the mechanisms mentioned above.

At least two subspecies of *S. maurus* occur in Israel: *S. maurus fuscus* H. et E., which varies in color from light to dark brown, and *S. maurus palmatus* H. et E., which is yellow (*4*). Both these subspecies produce sound by rapidly striking the posterior half of the mesosoma against the ground. While they are doing so, their pedipalps are flexed, the tail is brought over the mesosoma until it is almost touching it, and the body vibrates rapidly in a forward-upward, backward-downward direction. No other part of the body, such as the chelicerae, pectines, or aculeus, is involved in this reaction. In *S. maurus palmatus* each strike is accompanied by a few very rapid vibrations of the body which are performed without hitting the ground, so that the effect produced is that of a series of very rapid, successive, clearly audible thuds. *Scorpio maurus fuscus* was observed to hit the ground at a higher frequency; the motion is so rapid that it is difficult to ascertain whether each jerk actually hits the ground or not. In this case the successive thuds merge into a rattle.

Unlike the hissing of *Opisthophthalamus*, which may precede an encounter between two specimens, but will not occur after the two have come into actual contact, as stated by Alexander (*2*), *Scorpio maurus* may produce sound after a fight with another specimen. This response was witnessed also when a scorpion was following a locust which it failed to catch.

Among *S. maurus fuscus* a smaller form (possibly another subspecies) occurs, the adults of which do not surpass 5 cm in length. In this case similar vibrations were also observed in the