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TOTAL BODY ELECTRICAL CONDUCTIVITY (TOBEC) TO ESTIMATE TOTAL BODY FAT OF FREE-LIVING BIRDS[1]

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Abstract. Traditional methods to determine total body fat are undesirable under many circumstances because they require sacrificing individual birds. Walsberg (1988) recently introduced the total body electrical conductivity (TOBEC) method for total body fat to ecological studies. In this paper we expand on Walsberg's (1988) seminal paper and show that: (1) TOBEC is accurate under a narrow array of body masses, and is therefore appropriate for intraspecific studies; (2) dead birds exhibit significantly different TOBEC than live birds; and (3) the use of metal bands does not affect TOBEC measurements. We conclude that TOBEC provides an accurate estimate of total body fat, that it is preferable to traditional methods because it does not require sacrificing the bird, measurements can be taken quickly in the field, and (most importantly to field ornithologists) body fat can now be tracked through time for individual, free-living birds.

Key words: *Fat; body composition; TOBEC; methods; electrical conductivity.*

INTRODUCTION

Traditional methods to measure total body fat in birds are based on solvent extraction (i.e., Bligh and Dyer 1959) and require collecting and sacrificing individuals. These methods are undesirable under many circumstances, particularly when large sample sizes are required, when endangered or declining species are involved, or when it is necessary to follow the fat deposits of individual birds repeatedly through time.

An alternative, nondestructive method for estimating total body fat which uses total body electrical conductivity (TOBEC) was developed in the early 1970s and is based on the Harker Principle: an oscillating magnetic field can sense conductivity by detecting changes in a radiating coil's impedance (Presta et al. 1983, Anonymous 1989). Since the conductive properties of fat and fat-free mass are very different, the total lean mass in a given sample can be determined. This method differs from the earlier BIA method (bioelectrical impedance analysis) in that BIA requires an arrangement of electrodes to be positioned at various parts of the body, while TOBEC utilizes a coil surrounding the subject, thereby improving standardization (Bracco et al. 1983). Commercial devices are currently available that permit the estimation of the lean mass of an unknown sample using TOBEC. Total fat is the difference between total mass and lean mass.

The TOBEC method has been known in biomedical and agricultural research since the late 1970s, but has only recently been applied more extensively to humans and domestic and laboratory animals (Domermuth et al. 1976, Bracco et al. 1983, Presta et al. 1983, Van Loan et al. 1987, Keim et al. 1988, Van Loan and Mayclin 1987, Cochran et al. 1989, Hergenroeder et al. 1989, and others). Walsberg (1988) introduced the use of TOBEC in ecological studies and found an excellent agreement between total body fat measured using TOBEC and traditional extraction techniques for 14 species of birds ranging in mass from 14.6 g to 170 g ($R^2 = 0.988$ for a quadratic relationship).

We expand on Walsberg's (1988) study in this paper, asking three questions that relate to the use of this method:

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(1) Does the accuracy of the method remain high under a much narrower range of body masses? Since Walsberg's (1988) study used several species of different body masses, it is possible that the precision of the method could be lost under a narrower set of body masses.

(2) Does TOBEC differ between dead and live animals? This relates to the use of dead animals to build calibration curves.

(3) Does the presence of a metal band on the bird affect the measurements? In field studies, birds must be individually marked with metal bands for identification during subsequent captures. Metal bands are difficult to remove, however, and the utility of this technique would be enhanced if fat determinations were not sensitive to bands on birds.

METHODS

Thirty-eight birds of five different species ranging in mass from 18 g to 90 g were captured using mist nets or live traps. They were introduced into an EM-SCAN SA-1 Small Animal Body Composition Analyzer (available for ca. $5,800 from EM-SCAN, 3420 Constitution Drive, Springfield, IL 62707, Phone 217-793-3666; essentially the same device used by Walsberg) for approximately 5 sec, and the electrical conductivity index (EMSCAN) was recorded using:

$$\text{EMSCAM} = (S - E)/R$$

where S = Measurement with sample, E = Empty measurement, and R = Reference number (See Walsberg 1988 for detailed instructions).

Birds were then immediately sacrificed by thoracic compression (cardiopulmonary, AOU 1988) and dried to constant mass in a convection oven at 60°C. Subsamples were extracted for fat with petroleum ether and chloroform using a Goldfisch apparatus for 3 hr (Dobush et al. 1985). Total body fat was defined as the difference between total body mass and lean mass. The electrical conductivity index obtained with the analyzer was regressed against Goldfisch lean mass determinations.

A subsample of 12 *Passer domesticus* were measured alive in the TOBEC apparatus between four and six times each to determine the coefficient of variation associated with position within the chamber. Another subsample of 20 individuals of four shorebird species were also measured while alive using the TOBEC method, and then remeasured 4 hr after death. The shorebirds were then banded with U.S. Fish and Wildlife Service metal bands and remeasured a third time.

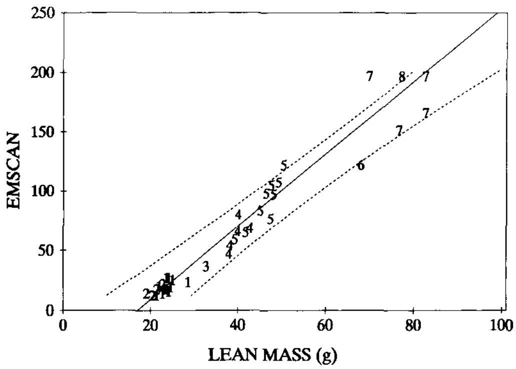

FIGURE 1. EMSCAN conductivity index plotted vs. lean mass (L) determined using the Goldfisch apparatus. Confidence intervals (95%) shown. Symbols: (1) *Passer domesticus*, (2) *Calidris pusilla*, (3) *Calidris fuscicollis*, (4) *Phalaropus tricolor*, (5) *Calidris himantopus*, (6) *Charadrius vociferus*, (7) *Gallinago gallinago*, and (8) *Limnodromus scolopaceous.*

STATISTICS

To estimate the accuracy of TOBEC, a relation between the EMSCAN number and lean mass (determined with the Goldfisch apparatus) needs to be derived. Since it is necessary to predict lean mass using the EMSCAN number in future instances, several researchers have presented regressions using lean mass as the dependent variable, and EMSCAN as the independent variable (i.e., Presta et al. 1983, Van Loan and Mayclin 1987, Cochran et al. 1989). This procedure is inappropriate, because it assumes that the EMSCAN number is measured without error, even though the hypothesis under test is the validity of EMSCAN when compared with traditional extraction techniques (Sokal and Rohlf 1981, p. 497).

Walsberg (1988) circumvented this problem by utilizing the EMSCAN number as the dependent variable and lean mass as the independent variable in a quadratic model. The resulting equation can then be algebraically rearranged to predict lean mass using the EMSCAN number. Confidence intervals can be calculated by the inverse regression procedure for a polynomial case (Draper and Smith 1981).

Consequently, we regressed (EMSCAN) as the dependent variable vs. lean mass determined with the Goldfisch apparatus as the independent vari-

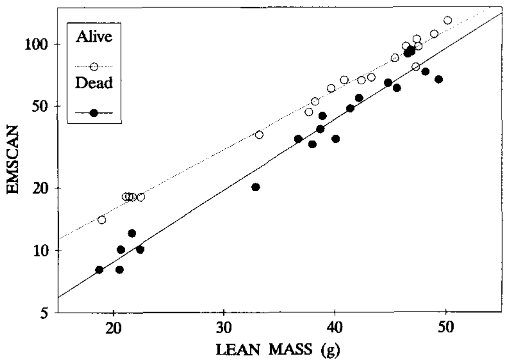

FIGURE 2. Calibration curves for dead and live birds.

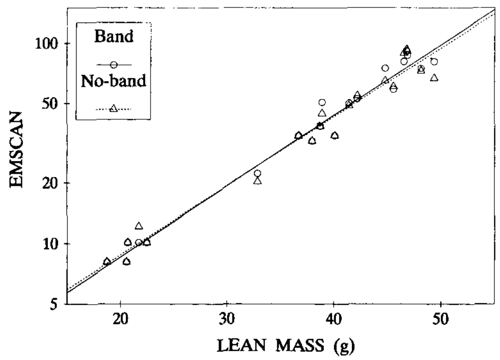

FIGURE 3. Comparison between banded and unbanded birds.

able. Confidence intervals were calculated by the inverse regression procedure for the linear case (Sokal and Rohlf 1981). All statistics were calculated using the statistical package SYSTAT 3.0.

RESULTS AND DISCUSSION

ACCURACY

The coefficient of variation of EMSCAN associated with position within the chamber averaged 6.8% (n = 78; 12 individuals).

The conductivity index (EMSCAN) was related to the lean mass (L) determined using the Goldfisch apparatus by (see Fig. 1):

$$\text{EMSCAN} = 2.71 \times \text{L} - 42.66$$

$$(r^2 = 0.95;\ P < 0.0001;\ n = 38;\ \text{SE} = 13.14)$$

The lean mass in subsequent determinations can be predicted by the equation:

$$\text{L} = (\text{EMSCAN} + 42.66)/2.71$$

The 95% confidence intervals associated with this predictive equation are also shown on Figure 1.

It should be noted that these intervals are not symmetrical around the mean. The accuracy of the method (measured by these confidence intervals) is good throughout the range of lean masses used. A lean mass of 20 g is probably the lower limit of resolution for the specific device used in this study (although at this lower range it will be necessary to obtain repeated measurements of each individual to minimize the effect of position), and the accuracy of the method is high enough to provide good estimates of lean mass (and total body fat) in intraspecific studies. The applicability of this method in specific studies, however, must be decided by other investigators based on the particular questions asked.

USE OF DEAD BIRDS

The use of this device by other investigators creates the practical problem of building calibration curves for other machines. We explored the use of dead birds to build the calibration curve by measuring the same individuals alive and dead (see Methods). Dead birds had significantly lower conductivities (Data was log-transformed, Fig. 2, ANCOVA: slope $P < 0.002$; intercept $P < 0.0001$; $n = 20$). Therefore calibration curves using dead birds are not applicable to live birds. This difference is probably the result of differences in temperature between live and dead birds, as the device is sensitive to changes in temperature (Walsberg 1988) and dead birds were at equilibrium with room temperature (approximately 20°C).

USE OF METAL BANDS

The use of U.S. Fish and Wildlife Service metal bands (of high conductivity) did not significantly alter TOBEC (data was log-transformed, Fig. 3, ANCOVA: slope $P > 0.583$; intercept $P > 0.742$, $n = 20$). Consequently, birds can be measured while wearing a metal band without apparent bias to the body fat estimate.

CONCLUSION

In conclusion, electrical conductivity can be used accurately to predict lean mass (and total body fat) in live birds. This method is precise enough for intraspecific studies. Dead birds exhibit different TOBEC than live birds. Metal bands used in banding do not alter measurements.

This method provides a straightforward, simple way of estimating total body fat in live birds, and will bring quick progress to many areas of ecological studies. A particularly attractive application is the use of total body fat as an indicator of the physiological condition of birds across, and between, seasonal life history events.

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