Evaluation of Multifrequency Bioelectrical Impedance Analysis for the Assessment of Extracellular and Total Body Water in Healthy Cats

Denise A. Elliott, Robert C. Backus, Marta D. Van Loan* and Quinton R. Rogers

Department of Molecular Biosciences, School of Veterinary Medicine, University of California–Davis, Davis, CA and *U.S. Department of Agriculture Western Human Nutrition Research Center, Davis, CA

EXPANDED ABSTRACT

KEY WORDS: • multifrequency bioelectrical impedance analysis • body composition • total body water • extracellular water • bioimpedance

Multifrequency bioelectrical impedance analysis (MF-BIA) is a promising, noninvasive, rapid, safe, portable, reproducible, electrical method of assessing body composition that has the potential to quantify total body water (TBW), extracellular water (ECW) and intracellular water (ICW), and thereby enable prediction of the fat-free mass (FFM), fat mass (FM) and body cell mass (BCM) (1). To our knowledge, there have not been any reports evaluating the use of MF-BIA in cats. The purpose of this study was to develop the scaling constants and assess the effects of animal position, animal length measurement and electrode configuration on the volume prediction accuracy of the Hydra ECF/ICF Bioimpedance Analyzer (Model 4200; Xitron Technologies, San Diego, CA) compared to TBW estimated by deuterium water (D₂O) space and ECW estimated by bromide (Br) space in healthy cats.

MATERIALS AND METHODS

The experimental protocols adhered to the NIH guidelines and were approved by the Animal Use and Care Administration Advisory Committee of the University of California at Davis. Twenty adult domestic shorthair cats (5 M, 5 F, 5 MC, 5 FS) were evaluated. All cats were considered to be healthy on the basis of physical examination. The cats were weighed to the nearest 0.01 kg and body condition score was scored using a five-category subjective body condition scoring system, where 1 = thin, 2 = lean, 3 = ideal body condition, 4 = heavy, 5 = obese. Morphometric measurements were obtained on the right side of the cat with the cat in a normal standing position using a flexible tape graduated in millimeters (Fig. 1). The height was recorded from the ground to the dorsal border of the scapula (a, scapula height) and the ground to the dorsal border of the pelvis (b, pelvic height). The length was determined from the external occipital protuberance to the base of the tail (c, head to tail), from the lateral canthus of the eye to the base of the tail (d, eye to tail), and from the tip of the nose to the base of the tail (e, nose to tail).

Blood samples were collected for background concentrations of deuterium and bromide. Tracer doses of D₂O (0.4 g/kg BW, deuterium oxide 99.8 APE; Cambridge Isotope Laboratories, Andover, MA) and NaBr (30 mg/kg BW, NaBr, ACS reagent assay > 99%; Sigma Chemical, St. Louis, MO) were administered intravenously after food and water were withheld for 24 h. An additional venous blood sample was obtained after a 90-min equilibration period to determine the concentration of the dilutional indicators. Concentrations of D₂O in condensed water were determined in duplicate using Fourier transform infrared spectroscopy (2). Bromide concentrations were assessed by high-pressure liquid chromatography (3).

Each cat was anesthetized with ketamine (1 mg/kg IV, to effect; Ketalar; Parke-Davis, Morris Plains, NJ), and diazepam (0.5 mg/kg IV, to effect; Valium; Roche Laboratories, Nutley, NJ) and positioned on a nonconductive table. Intradermal tetrapolar platinum electrodes (Grass platinum subdermal 27-gauge needle electrodes; Astro-Med, West Warwick, RI) were positioned at the external occipital protuberance on and perpendicular to the dorsal midline and the tail base on and perpendicular to the dorsal midline (body); the lateral condyle of the right humerus and the lateral aspect of the proximal tibia at the level of the femorotibial joint (contralateral) (Fig. 1). MF-BIA measurements were performed with a Hydra ECF/ICF Bioimpedance Analyzer connected to the corresponding intradermal electrodes while the cat was positioned in sternal recumbence. Ten measurements of resistance (R) and reactance (X) were obtained, and the corresponding impedance and phase angle were computed from R and X at 50 frequencies ranging from 5 to 1000 kHz. MF-BIA measurements were repeated with the cat positioned in left lateral recum-
bence, using all electrode arrays. The path lengths between each of the tetrapolar electrode configurations were recorded using a flexible tape graduated in millimeters. Six MF-BIA configurations were evaluated: sternal ipsilateral (SI), sternal contralateral (SC), sternal body (SB), left lateral ipsilateral (LLRI), left lateral contralateral (LLRC) and left lateral body (LLRB).

The generated Z- and two-spectral data for each electrode array and body position were fitted to an enhanced version of the Cole–Cole model of current conduction through heterogeneous biological tissues using iterative nonlinear curve-fitting algorithms derived for use with the Hydra Bioimpedance Spectrometer (1). The enhanced modeling program extends the original Cole–Cole model to allow for the frequency-invariant time delays caused by the speed at which electrical information is transferred through a conductor to yield the resistance of extracellular fluid (RE) and intracellular fluid (RI), respectively (1). The apparent resistivity constants of the ECW and ICW were determined by the iterative prediction of V<sub>ICW</sub>/V<sub>ECW</sub> for each configuration. The values for ECW and ICW were predicted from the modeled RE and RI using equations formulated from Hanai’s mixture theory, which describe the effects of nonconductive material on the apparent resistivity of the surrounding conductive fluid (1).

In addition to descriptive statistics, relationships among variables were determined by analysis of variance, general linear models procedure and least-squares linear regression techniques using standard statistical software (Statistical Analysis System; SAS Institute Inc., Cary, NC). Bland–Altman plots were constructed to display differences between the MF-BIA predicted and the D<sub>2</sub>O determined TBW, and the MF-BIA predicted and the Br determined ECW. All data were expressed as means ± SE unless otherwise noted. Any value of P < 0.05 was considered significant.

RESULTS

The mean age of the 20 healthy cats was 5.51 ± 0.69 y, mean body weight was 5.28 ± 0.24 kg, and mean body con-
dition score was 4.0 ± 0.2. The mean deuterium determined TBW of the 20 cats was 2.62 ± 0.09 L (median 2.67 L, range 1.70–3.27 L), and the mean volume of the bromide determined ECW was 1.01 ± 0.04 L (median 1.09 L, range 0.63–1.34 L). There were no significant differences between the dilution determined and the MF-BIA determined TBW or ECW.

The MF-BIA configuration that had the smallest standard error of the estimate (SEE) compared with that of the D₂O determined TBW was the sternal contralateral path-length (SCP) configuration (r = 0.84, SEE = 0.26 L). The difference between the D₂O determined and the MF-BIA (SCP) determined TBW was −0.0001 ± 0.06 L, and the limits of agreement were −0.50 to 0.50 L (Fig. 2). Conversely, the MF-BIA configuration that had the largest SEE compared with that of the D₂O determined TBW was the left lateral body scapula height (LLRBSH) configuration (r = 0.41, SEE = 0.62 L). The difference between the D₂O determined and the MF-BIA (LLRBSH) determined TBW was 0.0001 ± 0.14 L, and the limits of agreement were −1.22 to 1.22 L (Fig. 2).

The MF-BIA configuration that had the smallest SEE compared with that of the bromide determined ECW was the sternal body head to tail (SBHT) configuration (r = 0.91, SEE = 0.07 L). The difference between the bromide determined and the MF-BIA (SBHT) determined ECW was 0.0001 ± 0.02 L, and the limits of agreement were −0.16 to 0.16 L (Fig. 3). Conversely, the MF-BIA configuration that had the largest SEE compared with that of the bromide determined ECW was the left lateral contralateral head to tail (LLRCHT) configuration (r = 0.74, SEE = 0.15 L). The difference between the bromide determined and the MF-BIA (LLRCHT) determined ECW was 0.0001 ± 0.03 L, and the limits of agreement were −0.30 to 0.30 L (Fig. 3).

This study has demonstrated that MF-BIA can be used to estimate TBW and ECW in healthy cats. The technique is safe, noninvasive, portable, simple and provides instantaneous results. It remains to be demonstrated that the predictive equations for TBW and ECW developed in these healthy adult cats will provide reliable and accurate estimates of TBW and ECW in additional populations of healthy cats. In addition, further research is needed with the MF-BIA method to determine its accuracy in healthy geriatric cats, kittens, cats during pregnancy and lactation, and in hospitalized cats.

LITERATURE CITED