LETTERS TO THE EDITOR

- The British Heart Journal welcomes letters commenting on papers that it has published within the past six months.
- All letters must be typed with double spacing and signed by all authors.
- No letter should be more than 600 words.
- In general, no letter should contain more than six references (also typed with double spacing).

Non-invasive determination of cardiac output by Doppler echocardiography and electrical bioimpedance

SIR,—Dr Northridge and colleagues (1990;63:93-7) have, inadvertently I am sure, incorrectly cited the proper name of the stroke volume equation currently implemented in NCCOM3. While it is true that the general form of the equation of Sramek *et al.*¹ quoted under patients and methods, describes impedance derived stroke volume in a general, qualitative fashion, it is the quantitative definition of volume of electrically participating tissue (VEPT) in the equation that requires clarification.

In the work cited by Northridge and associates, the VEPT defined by Sramek *et al.*¹ is determined in practice uniquely as a function of body height alone. However, as correctly stated by Northridge *et al.*, VEPT as currently used is a constant derived from both body height and weight. NCCOM3 computes stroke volume from the Sramek equation corrected for body habitus.^{2,3} This modified equation is now generally cited as the Sramek-Bernstein equation,^{4,7} which is the one, apparently, used in this study.

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- 1 Sramek BB, Rose DM, Miyamoto A. Stroke volume equation with a linear base impedance model and its accuracy, as compared to thermomodulation and magnetic flow meter techniques in humans and animals. Proceedings of the sixth conference on electrical bioimpedance, Zadar, Yugoslavia, 1983:38.
- 2 Bernstein DP. A new stroke volume equation for thoracic electrical bioimpedance: theory and rationale. *Crit Care Med* 1986;14:904-9.
- 3 Gotshall RW, Wood VC, Miles DS. Comparison of two impedance cardiographic techniques for measuring cardiac output in critically ill patients. *Crit Care Med* 1989;17:806-11.
- 4 Appel PL, Kram HB, MacKabee J, Fleming AW, Shoemaker WC. Comparison of measurements of cardiac output by bioimpedance and thermomodulation in severely ill surgical patients. *Crit Care Med* 1986;14:933-5.
- 5 Goli VD, Teague SM, Prasad R, *et al.* Non-invasive evaluation of aortic stenosis severity utilizing Doppler ultrasound and electrical bioimpedance. *J Am Coll Cardiol* 1988;11:66-71.
- 6 Masaki DI, Greenspoon JS, Ouzounian JG. Measurement of cardiac output in pregnancy by thoracic electrical bioimpedance and thermomodulation. *Am J Obstet Gynecol* 1989;161:680-4.

- 7 Tibbals J. A comparative study of cardiac output in neonates supported by mechanical ventilation: measurement with thoracic electrical bioimpedance and pulsed Doppler ultrasound. *J Pediatr* 1989;114:632-5.

SIR,—We read with interest the validation of the transthoracic bioimpedance cardiac output device (BoMed NCCOM3) in acute myocardial infarction (1990;63:93-7). Northridge *et al.* concluded that in most patients the transthoracic electrical bioimpedance technique was accurate and reproducible. The validity of this technique has been questioned¹; we recently concluded that impedance cardiac output as implemented in the BoMed NCCOM3 was "not accurate compared with the thermomodulation reference nor was it quantitative".²

There are many pitfalls in the assessment of cardiac output and in undertaking validation studies in humans³ and assessment of devices likely to be applied in critical care should be rigorous rather than enthusiastic. Validation in vitro and in vivo should be attempted, the method should be accurate compared with the reference standard, and show similar reproducibility with ability to track physiological events and the effects of pharmacodynamic interventions.⁴ A simple rest assessment may have serious limitations and result in misleading conclusions.

Several crucial points in the Northridge paper may have contributed to the outcome. It is unclear whether investigators were blind to each other—this should be mandatory to avoid unconscious bias. Ten averaged estimates of impedance cardiac output were compared with three averaged thermomodulation estimates: this is not reasonable. After the establishment of control haemodynamic stability, measurements should be paired, simultaneous, and consecutive; discarding of data ("outliers") and averaging generates spurious accuracy. The reference thermomodulation system is at best under conditions of physiological stability.⁵ Perusal of the data on control cardiac output (3.95 l/min) indicates that this lies outside the 95% confidence limits for acute heart failure (mean 4.31 (95% confidence interval +0.16) based on 32

studies of acute heart failure⁶); this suggests haemodynamic compromise, with subjects unlikely to be haemodynamically stable. Validation studies should cover as wide a range of comparison points to ensure the method has no systematic bias; clearly this was not achieved because of the patient population selected. In three of the patients there were considerable discrepancies between the methods—were these with higher cardiac outputs?

Our assessment of the BoMed impedance device in 16 patients with stable coronary disease was as follows.⁷ Ten consecutive cardiac output measurements were compared with 10 impedance estimations over a 15 minute period. Subjects were studied fasting without premedication after a period of sub-maximal exercise to minimise haemodynamic variability. Observers were blind to each other; the thermomodulation method had previously been validated in vitro and in vivo with accuracy and reproducibility determined.⁸ Data were not averaged and all data were included to obviate observer bias. The data (figure) clearly suggested large discrepancies between the impedance estimate of cardiac output and the thermomodulation reference (average difference 1.33 l min⁻¹ m⁻²; 95% limits of agreement 0.13 to 2.79 l min⁻¹ m⁻²). During 4 minutes supine bicycle exercise, with techniques to minimise chest movement, these differences increased (average difference 2.36 l min⁻¹ m⁻²; 95% limits of agreement -0.56 to 5.28 l min⁻¹ m⁻²). We concluded that the BoMed impedance method as currently implemented in the NCCOM3 device produced uniformly low values compared with thermomodulation estimates, suggesting that the incorporated algorithms were not appropriate to the ischaemic population. Our observations suggested that the method at present is unacceptable for scientific or clinical applications.

Devices which rely on empirically determined formulas (impedance changes in transthoracic impedance have been correlated with cardiac stroke output in volunteers) depend absolutely on the reliability of these relations; it may be oversimplistic to expect similar volume conduc-

Validation of transthoracic bioimpedance (TEI) method.