

As expected, we obtained similar results when applying (10) and (12) since the hypotheses assumed for the simplification were met during our measurements. First, the frequency responses of transducers, pneumotachograph, and filters were compensated. Second, the volume of air inside the pneumotachograph was only 11 cm<sup>3</sup>, giving gas compression negligible up to 32 Hz. Third, the tube connecting the outlet of the pneumotachograph with the point where excitation pressure was measured had a length of 4 cm and an internal diameter of 2.8 cm allowing us to neglect  $\beta_H$ . Nevertheless, application of the simplified correction, (12), could not be used under different circumstances, for instance, at high frequencies where shunt impedances play a larger role.

In conclusion, we established a general model for the most common setup used to measure respiratory input impedance. From this theoretical basis, we also devised a simple calibration and data correction procedure. The latter was shown to adequately correct very large errors due to transducer asymmetry. With this approach, even highly asymmetrical differential pressure transducers can be used to measure respiratory input impedance. This is already of interest in the usual frequency range. Moreover, it permits measurements at higher frequencies where a high enough common-mode rejection ratio of the differential pressure measuring system is difficult to obtain.

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#### Authors' Reply

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AND J. D. SWEENEY

We disagree with the opinions expressed by Dr. Racz and Dr. Heavner regarding our recent paper<sup>1</sup> and we believe that their comments serve little constructive purpose. Racz and Heavner do not criticize any specific aspect of our work; rather, they appear to reference our paper as a means of establishing a forum through which to discuss their own work with a different type of electrode. They express the opinion that "cuff electrodes for peripheral nerve stimulation have little future." They support their opinion by citing the "history" of cuff electrodes. Presumably, this is a reference to the problems of tissue damage and nerve irritation that have sometimes been associated with these electrodes—problems which we summarized clearly in the introduction to our paper. Indeed, Dr. Racz and Dr. Heavner seem to have missed the whole point—that we devised the self-sizing spiral cuff design with the intent of

#### Comments on "A Spiral Nerve Cuff Electrode for Peripheral Nerve Stimulation"

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#### INTRODUCTION

We are of the opinion that cuff electrodes for peripheral nerve stimulation have little future. Our poor prognosis is based upon the

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<sup>1</sup>G. G. Naples, J. T. Mortimer, A. Scheiner, and J. D. Sweeney, *IEEE Trans. Biomed. Eng.*, vol. 35, pp. 905-916, 1988.

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<sup>1</sup>G. G. Naples, J. T. Mortimer, A. Scheiner, and J. D. Sweeney, *IEEE Trans. Biomed. Eng.*, vol. 35, pp. 905-916, 1988.

overcoming these problems. There certainly is further work to be done before self-sizing cuffs can be applied to human subjects, but we believe it is irresponsible to imply that such work serves little purpose.

Racz and Heavner advocate the use of "electrodes similar to or exactly like those used for epidural spinal cord stimulation"—electrodes which we will refer to in this context as "epineural." They state that their approach eliminates the problem of nerve irritation, but they provide no histopathological evidence to support this opinion [8], [9]. Furthermore, they state that the "availability of four contact points through which to stimulate and the availability of programming a stimulation pattern, and the ability to change this stimulation pattern, offer distinct advantages." They do not elaborate on this statement, but presumably they are referring to the ability to activate discrete regions of a single nerve trunk. When several "contact points" (i.e., electrodes) are made available in close proximity to one another upon a nerve, it is possible to manipulate the electric field generated by the collective electrode array by varying both the current balance between the various electrodes and the timing with which the electrodes are stimulated. By altering the electric field, it may be possible to control which specific axons, or groups of axons, are stimulated at a given moment. This ability to customize the neural stimulation pattern may enable the programmer to optimize the stimulation system to the needs and neural anatomy of each patient.

We do not dispute the clinical utility of epineural electrodes. There is evidence, in addition to that provided by Racz and Heavner, that when properly implanted, epineural electrodes can be quite benign [1], [6]. In addition, other groups have utilized multiple epineural electrodes in neuroprosthetic applications and have demonstrated the ability to stimulate particular regions of a single nerve [1], [4], [6]. We have investigated this ability ourselves with cuff electrodes [11], [12], as have others [5], [7]. For this purpose, and in other specialized neuroprosthetic applications [2], [3], [10], the insulation of cuffs can provide a structure for precise longitudinal and circumferential placement of electrodes, and can be used to constrain current flow to desired pathways. Indeed, Racz and Heavner appear to have overlooked a key point in our original paper—that for some specialized applications the use of cuffs is either essential or highly advantageous.

We did not, and do not, contend that self-sizing cuff electrodes are a panacea for the problems associated with the use of nerve stimulation electrodes. On the contrary, we believe that the properties of each electrode type will dictate whether it is appropriate for use in a given application. Therefore, it is our opinion that no electrode design should be dismissed as having little potential utility in neuroprosthetic technology.

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### Comments on "Analytical Solution to the Three-Compartment Pharmacokinetic Model"

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#### INTRODUCTION

In the paper "Analytical solution to the three-compartment pharmacokinetic model,"<sup>1</sup> Jacobs provides a general analytic solution to the three-compartment model. Unfortunately, the resulting solution, although correct for central compartment concentration determination, may be misinterpreted.

The state equations given by Jacobs are

$$\frac{dC_1}{dt} = \frac{k_0}{V_1} - [k_{10} + k_{12} + k_{13}]C_1 + k_{21}C_2 + k_{31}C_3 \quad (1)$$

$$\frac{dC_2}{dt} = k_{12}C_1 - k_{21}C_2 \quad (2)$$

$$\frac{dC_3}{dt} = k_{13}C_1 - k_{31}C_3. \quad (3)$$

The reader might infer that  $C_2$  and  $C_3$  represent the concentrations in the two peripheral compartments. If so, (2) and (3) imply that the transfer of drug between two compartments depends on a weighted concentration difference. In fact, the laws of diffusion are more specific: transfer depends on a simple concentration difference. Thus, the proportionality constants on the right-hand side of each equation must be equal.

The set of equations which satisfies both passive diffusion and conservation of mass is

$$\frac{dM_1}{dt} = a_0 - a_{10}C_1 - a_{12}(C_1 - C_2) - a_{13}(C_1 - C_3) \quad (4)$$

$$\frac{dM_2}{dt} = a_{12}(C_1 - C_2) \quad (5)$$

$$\frac{dM_3}{dt} = a_{13}(C_1 - C_3) \quad (6)$$

where  $a_0$  is the rate of infusion,  $a_{ij}$  is the rate of mass transfer from compartment  $i$  to compartment  $j$ ,  $a_{10}$  is the rate of mass elimination

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