CONCLUSION

The system described may be considered superior to conventional solenoid valve systems because it assures:

i) high reliability
ii) high speed of response;
iii) low power consumption (electric);
iv) low weight;
v) the possibility of sterilization.

Extensive clinical tests are imperative for properly evaluating the system. Lack of facilities prevented this from being carried out.

Capabilities of intra-aortic balloon pumping have already been established. It is hoped that the fluidic drive developed would result in safer, more reliable, and economical system.

REFERENCES

[1] John W. Clark *et al.*: 'On feasibility of closed-loop control of intra-aortic balloon pumping,' *IEEE Transactions on Biomedical Engineering*, vol. BME-20, No. 6, November 1973.
[2] Ludwig Wolf *et al.*: 'Mock Circulatory System for Intra-aortic Balloon Pumping,' *IEEE Transactions on Biomedical Engineering*, vol. BME-19, No. 1, January 1972.
[3] *A Guide to Fluidics*, Edited by Arthur Conway, MacDonald–Elsevier, London, New York, 1971.

Electromagnetic Syringe

LEONARD S. TAYLOR

Abstract—A device is described which can be used as a "hyperdermic syringe" to inject electromagnetic energy into deep-lying tissues.

In this communication, we describe a device for direct injection of radio frequency and microwave fields into deep tissues *in vivo*. The device has possible application in diathermy and in experiments upon the effect of electromagnetic fields on biological systems. For example, a basic difficulty in the diathermy of deep lying tissue is that, if the tissue is heated by an external radiator, the field is attenuated by the intervening tissue, which is heated to a high temperature. Direct injection by a hyperdermic syringe can avoid this difficulty. Similarly, a variety of animal experiments have been carried out to test the effects of microwave fields. However, these experiments have generally been limited to the use of whole body irradiation so that specific effects on organs are not readily discernible. The use of an electromagnetic syringe can remove this limitation.

The syringe described here consists of a subminiature rigid coaxial waveguide which connects to the generator at one end and terminates in a needle-like configuration which radiates the field at the other end. A coaxial guide is necessary, of course, since it has no low-frequency cutoff. The radiator is obtained, simply, by open-ending the outer conductor and having the inner conductor extend out beyond for the proper length. The reader's attention is directed to the point that such a radiator can only be effective when embedded in a lossy dielectric; only a small fraction of the power will be radiated into free space, for example, because of the large mismatch the element presents to the generator in this case. We found little difficulty, however, in constructing a needle radiator which effected a VSWR <1.1 at 2450 MHz when the radiator was embedded in a phantom material which has the same dielectric permittivity and loss tangent as human muscle tissue. In the first trials, the syringe consisted of commercial 2.16-mm (0.085-in)-O.D. coaxial Teflon-filled waveguide, connected by standard connectors and cable to the microwave generator. At the radiating end, the inner conductor was extended 1.7 cm out to achieve the match mentioned above. In the second trials, the syringe was constructed using 0.76-mm (0.030-in)-O.D. cable. A photograph of this device is shown in Figure 1. The diameter is close to that of a 22-gm hyperdermic needle. At the radiating end, the inner conductor has been extended 0.6 cm to achieve a VSWR = 1.7 under the conditions mentioned above, representing a good compromise between mechanical strength and electrical efficiency.

In order to determine the heating pattern effected by the device, the radiator, where placed between the halves of a styrofoam) mold with a spherical cavity (radius ~8 cm), filled

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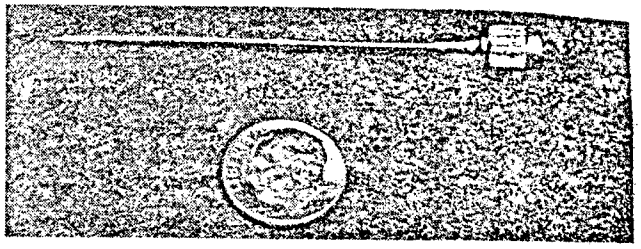

Figure 1. 2450-MHz Syringe (0.76-mm O.D.)

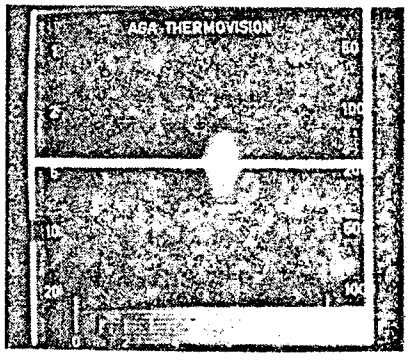

Figure 2. Thermograph of heating in phantom material: The heated region is approximately a 3 × 4.5-cm ellipsoid. The center of the ellipsoid is close to the outer conductor termination, the temperature profile [Figure 3] is taken along the horizontal line.

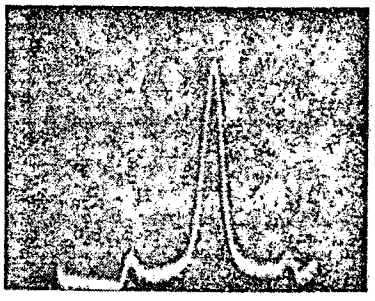

Fig. 3. Temperature profile in phantom material: The maximum temperature increase is 10°C. The width of the pattern is 2.0 cm at half-maximum.

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with phantom material. Microwave power was injected for a short period, the mold halves opened, and a thermograph photo (Figure 2) of the mold taken within a period short enough to eliminate the effects of thermal conduction. Typical results are illustrated below (Figure 3) for the 0.76-mm syringe for an injection of 25 W for 30 s, demonstrating the feasibility of this type of device for a variety of applications and experimental uses. Waveguides of the type used here are commercially available with diameters down to 0.20 mm, presenting the possibility for microwave injection into very delicate tissue.

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A Method for Measuring Functional Residual Capacity in Neonates with Endotracheal Tubes

JACOB G. SCHWARTZ, WILLIAM W. FOX, AND THOMAS H. SHAFFER

Abstract—This study evaluates a new 60-s closed circuit helium (He) dilution technique for determination of functional residual capacity (FRC) in intubated neonates independent of small gas leaks present around uncuffed endotracheal (ET) tubes. By analytically relating the fall in He concentration due to mixing with that due to leakage it is possible to predict the final equilibration concentration of He and, therefore, correct for ET tube leaks. The system (120 ml) contains an air pump, He meter, breathing bag in cylinder, a strip chart readout, and solenoid value. Continuous positive airway pressure (CPAP) or ventilator pressure can be applied during testing. One hundred *in vitro* measurements of FRC ranging from 5-100 cc in both leak and nonleak models were performed and were accurate to within ±7.8% standard deviation. Functional residual capacity measurements were also performed in 30 infants (weight 600-4400 gm).

INTRODUCTION

In the neonatal Respiratory Distress Syndrome (RDS) the two major pulmonary function abnormalities are decreased lung compliance and volume [1]. The lung volume at end-expiration or functional residual capacity (FRC) is an important diagnostic measure of alveolar stability and can be determined by indirect methods, including helium (He) dilution, nitrogen washout, and plethysmography [2-9]. However, the He dilution method [2] is the most widely used technique for clinical investigation in neonates because of its simplicity.

Since a large percentage of neonates with RDS are on various forms of respiratory therapy requiring endotracheal (ET) tubes, all of the above methods of determining FRC are subject to measurement errors due to gas or air leakage around the uncuffed ET tube [10, 11]. This study presents the theoretical and experimental aspects of a closed-circuit He dilution technique for determination of FRC in neonates. A mathematical consideration of He leak rates is compared to *in vitro* experimental results to investigate the feasibility of determining accurate FRC values in the presence of ET tube leakage. In addition, results of clinical tests and an evaluation of the suitability of the system and method for measuring FRC in newborn infants are presented.

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PROBLEM FORMULATION

With the He dilution technique for measuring FRC, the patient's lung volume is unknown and is determined with a closed system containing a known volume (V) and initial He concentration (C_i). After the patient rebreathes from the system for a short period of time, the He concentration in the lungs and system reaches a final equilibration value (C_f). Therefore, the FRC can be determined [12] as

$$\text{FRC} = V\left(\frac{C_i}{C_f} - 1\right). \tag{1}$$

For a nonleak procedure, the concentration of He can be expressed as an exponential function of time,

$$C_{\text{He}}(t) = C_f + (C_i - C_f)e^{-Et} \tag{2}$$

where E (units of seconds^{-1}) is a constant of equilibration based on a one compartment model of the lung [10].

In the procedure where a leak is present, it is assumed that the gas leaking around the ET tube is at the same concentration as the He in the lungs. Therefore, the amount of He that is lost during successive breaths can be expressed as an exponential function of time. The He concentration in the system and lungs can then be expressed as

$$C'_{\text{He}}(t) = (C_f + (C_i - C_f)e^{-Et})e^{-Lt} \tag{3}$$

where L (units of seconds^{-1}) is a constant of leak rate, and is a function of the infant minute ventilation and the physical size of the opening between the ET tube and trachea.

Since equilibration time is essentially complete after 30 s (determined in infants using a face mask) [2], it can be shown from equation (2) that for $t_2 > t_1 > 30$ s

$$C_{\text{He}}(t_1) = C_{\text{He}}(t_2) = C_f. \tag{4}$$

Also

$$C_f + (C_i - C_f)e^{-Et_1} = C_f + (C_i - C_f)e^{-Et_2} = C_f. \tag{5}$$

Simplifying equation (5) yields

$$(C_i - C_f)e^{-Et_1} = (C_i - C_f)e^{-Et_2} = 0. \tag{6}$$

Combining equations (3) and (6) results in

$$C'_{\text{He}}(t_1) = C_f e^{-Lt_1} \tag{7}$$

and

$$C'_{\text{He}}(t_2) = C_f e^{-Lt_2}. \tag{8}$$

Dividing equation (7) by (8) and solving for L yields

$$L = \frac{1}{t_2 - t_1} \ln\left[\frac{C'_{\text{He}}(t_1)}{C'_{\text{He}}(t_2)}\right]. \tag{9}$$

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