Measurement of ultrasound power using a calorimeter

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Abstract: This paper presents a comparison between the ultrasound power of a 1 MHz therapy equipment on the water using a calorimeter and a radiation force balance. For a range of 5 to 10 W, the results presented a normalized error less than 1, disclosing compatibility of the results from the developed system and the radiation force balance. The calorimetric method might be used as a faster and cheaper means for the verification of the ultrasonic power emitted by an equipment for physiotherapeutic treatment.

Keywords: Ultrasound Power, Radiation Force Balance, Physiotherapy, Calorimeter

1. INTRODUCTION

Therapeutic ultrasound equipment typically use frequency from 1 to 3 MHz and intensities ranging from 0.1 to 3.0 W cm^{-2} in continuous and pulsed modes. The equipment comprises a high frequency electric current generator and an amplifier, connected to a piezoelectric ceramic lead zirconate titanate (PZT) which deforms in the presence of an electric field. The radiation produced by ultrasound transducers finds increasing application in several areas of knowledge. In certain cases, it is necessary to know the applied power, especially in the medical field where it is widely used for diagnosis, therapy or surgical procedures.

Ultrasound is among the physical resources most used by professional physiotherapists in the treatment of the most diverse disorders of the musculoskeletal system. The intensity of the ultrasonic radiation is an essential factor for the success of any therapy, as well as its time of application.

The ultrasonic radiation effects on the tissues depend on its applied intensity. The ultrasound power should be calibrated in order to avoid lack of efficiency of the treatment. The equipment must be checked periodically to ensure that the standards are correct. According to Repacholi and Benwel [1], this energy depends on the following parameters: acoustic power, time, frequency, and effective radiation area of the transducer.

Typically, ultrasound power is measured with a radiation force balance. However, this measurement equipment is expensive and time consuming. Alternative way to assess physiotherapy equipment ultrasonic power would be of interest for equipment in clinical commitment.

The work reported in this paper aims to develop a calorimeter for the measurement of the ultrasonic power. Further, we compared the power output from an ultrasound therapy equipment for 1 MHz using as reference value the results from a radiation force balance.

2. METHODOLOGY

2.1. Heat Flux

For a body to be heated, normally a constant power source is used, that is, a source capable of supplying an amount of heat per unit of time.

We define the *heat flux* (ϕ) as the quotient between the *quantity of heat* (Q) and the *time interval of exposure* (Δt) and is given by the formula:

$$\phi = \frac{Q}{\Delta t} \qquad (1)$$

The unit adopted for heat flux in the International System is watt (W), corresponding to joule per second.

2.2 Thermal variation

Given the equation

$$Q = m \cdot c \cdot \Delta\theta \qquad (2)$$

in which Q is the *quantity of heat* (joule), $\Delta\theta$ is the *expected thermal variation* (°C) when the m *mass of water* (kg) is heated with a transducer of an ultrasound therapy equipment was obtained by the equation (4):

$$\Delta\theta = \frac{\phi \cdot \Delta t}{m \cdot c} \qquad (3)$$

in which, c is the *specific heat of water* equal to 4,1868 $J \cdot g^{-1} \cdot °C^{-1}$. The expected temperature increase by heating 250 g of water for 5 minutes, for the three nominal power is shown in Table 1.

Table 1. Expected thermal variation for 5 minutes of heating of 250 g of water.

Power [W]	$\Delta\theta$ [°C]
5,0	1,43
6,5	1,86
10,0	2,86

The sample temperature is monitored during the measurement process with the aid of a thermocouple type K and a temperature measuring system (model U1252A, Agilent Technologies, CA). Figure 1 illustrates the experimental setup of the measuring system described above:

Figure 1. Experimental arrangement used for determining ultrasonic power with the calorimeter.

2.3 Ultrasonic Power

The ultrasonic power estimated from the thermal variation was determined based on four measurements under repeatability conditions, for each power studied. The ultrasonic power is given by the equation:

$$P = \frac{m \cdot c \cdot (\Delta\theta)}{t} \qquad (4)$$

2.4 Measurement Uncertainty

The measurement uncertainty is a parameter that provides positive dispersion characteristics of a measured quantity. Here, the measurement uncertainty is calculated according to the Guide of the Expression of Uncertainty in Measurements.

Standard uncertainties Type A and Type B were considered. The standard uncertainty Type A was obtained by calculating the standard deviation of the mean for four repetitions. The standard uncertainty Type B was estimated from the temperature uncertainty acquired from the digital thermometer calibration (0.1 °C), the mass of water (5 g), specific heat of water ($0,0010\ J \cdot g^{-1} \cdot {}^{\circ}C^{-1}$), and time exposition (2 seconds).

According item 5.1.2 [7], the combined standard uncertainty uc_{power} is the positive square root of the combined variance, and is given by (5):

$$uc_{power} = \sqrt{\sum \left(\frac{\partial P}{\partial xi} \cdot u_{xi} \right)^2} \qquad (5)$$

The expanded uncertainty U_{power} was obtained by multiplying the combined standard uncertainty uc_{power} by a coverage factor k = 3.18 based on the t-distribution for $v_{eff} = 3$, with coverage probability of 0.95.

3. RESULTS

The measurement results of ultrasonic power obtained with the calorimeter *(P_cal)* and radiation force balance *(P_bal)*, with its respective uncertainties *(U_cal)* and *(U_bal)* are shown in Table 2.

Table 2. Measurement results of ultrasonic power obtained with the calorimeter, with its respective uncertainties

Nominal Power [W]	Force balance		Calorimeter	
	P_{bal} [W]	U_{bal} [W]	P_{cal} [W]	U_{cal} [W]
5.00	4.48	0.32	5.4	1.6
6.50	5.82	0.33	7.07	0.90
10.0	9.18	0.56	10.0	1.1

The results of ultrasonic power obtained with the calorimeter, compared to the ultrasonic power obtained with the force balance of radiation and the nominal power of the equipment are presented in Figure 2.
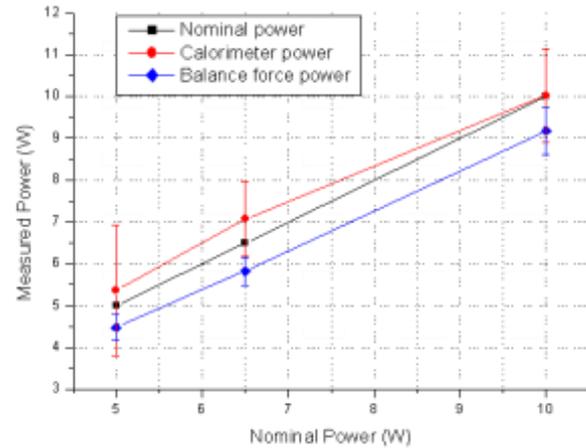

Figure 2. Relation between ultrasonic power obtained with the calorimeter, ultrasonic power obtained with the force balance of radiation and the nominal power of the equipment

Normalized error is a statistical evaluation used to compare proficiency testing results in which the uncertainty in the measurement result is included. Typically, it is the first evaluation used to determine conformance or non-conformance (i.e. Pass/Fail) in proficiency testing. The formula used for calculating the normalized error (E_n) is shown below. Values of $E_n < 1$ means that the results can be considered equivalent.

$$E_n = \left| \frac{P_{cal} - P_{bal}}{\sqrt{(U_{bal}^2 + U_{cal}^2)}} \right| \qquad (6)$$

The results of normalized error (E_n) are presented in Table3.

Table 3. Normalized Error (E_n)

Nominal Power [W]	E_n
5.0	0.56
6.5	1.30
10	0.66

4. CONCLUSION

Ultrasound is the physical resource mostly used by professional physiotherapists in the treatment of the several disorders of the musculoskeletal system. The intensity of the ultrasonic radiation is an essential factor for the success of any therapy, as well as it is the time of application. Here, we compared the results of the ultrasonic power measurements of a physiotherapy equipment obtained from the radiation force balance and a calorimeter. The results show that the expected temperature variation was achieved, but for a better accuracy in measurements, it will be necessary to use a thermometer with lower uncertainty. The largest component of uncertainty (90%) in the result obtained comes from calibration certificate of the thermometer. Larger temperature differences ($\Delta\theta$) would be obtained if a specific heat lower than water were used, for example, castor oil [4], specific heat equal to $1,8 \ J \cdot g^{-1} \cdot °C^{-1}$.

The normalized error less than 1, in two powers, attests the compatibility of the results of the measurements of the powers of the ultrasound equipment between the calorimeter and the reference value obtained from the balance of force of radiation.

5. REFERENCES

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