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Diagnostic Ultrasound Quality Assurance by Means of Machine Output Parameters

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Abstract

The out-put parameters in terms of average acoustic power and intensity levels from a diagnostic ultrasound machine located at General Hospital Gboko were measured using ultrasound power meter UPM-DT-10AV. The ultrasound power meter measures the out-put acoustic power from the ultrasound beams which were converted to intensity levels, three set of readings were taken for each of the pre-timed durations of 3,6,9,12,15,18,21,24,27 and 30 minutes, the average values were then found. The work has assed ultrasound dosimetry compliance in this Hospital and provide database for diagnostic ultrasound quality control for the Hospital. The machine has a minimum average intensity value of 0.04 ± 0.01 W/cm^2 at an exposed scanning duration of 3 minutes for both pulse wave and continuous wave propagation modes respectively. From the results, it can be seen that beyond scanning duration of 9 minutes the machine have out-put intensities beyond the maximum safe limit of 0.09 W/cm^2 for fetal imaging and other sensitive organs, also 0.017 W/cm^2 for ophthalmic scan, but within the maximum safe limit of 0.43 W/cm^2 for cardiac scan and 0.72 W/cm^2 for the scanning of the peripheral vessels.

Keywords: Diagnostic ultrasound, scanning durations, acoustic power and intensity levels.

1.0 Introduction

Ultrasound has been used by radiologists and sonographers to image the human body for at least 60 years now, and has become one of the most widely used diagnostic tools in modern medicine [1]. The technology is relatively inexpensive and portable, especially when compared with other techniques, such as Magnetic Resonance Imaging (MRI) and Computed Tomography (CT).

Measurement of power out-put levels of diagnostic and therapeutic ultrasound equipment has become increasingly important to determine exact patient exposure levels during routine measurements [2]. It has been over 40 years ultrasound was first used on pregnant women, unlike x-rays, ionizing irradiation is not present and embryo-toxic effects associated with such irradiation may not be relevant. However, WHO [3] report that the embryonic period is known to be particularly sensitive to any external influences. Until further scientific information is available investigations should be carried out with careful control of out-put limit and exposure times. Users should prudently limit exposure of critical structures such as the fetal skull or spine during Doppler studies [4].

An understanding of the issues related to propagation speed, impedance and attenuation of ultrasound in biological materials are directly applicable to the mathematical descriptions of biophysics mechanisms. The propagation properties generally use to describe quantitatively the propagation of ultrasound is assumed to be an adiabatic process; therefore, the speed at which ultrasonic energy propagates in a fluid is [5], [6] and [7].

$$C=\sqrt{\frac{B_{AD}}{\rho}} \qquad (1)$$

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Where the elastic modulus for an isotropic fluid isB_{AD}, the adiabatic bulk modulus and the medium's density is ρ. For a liquid, the elastic modulus is $B_{AD} = YB_T$, where B_T is the thermal bulk modulus, and therefore

$$C=\sqrt{\frac{YB_T}{\rho}} \quad (2)$$

In an isotropic solid, both longitudinal and shear waves are supported within their respective propagation speed and is given

$$C=\sqrt{\frac{Y(1-\sigma)}{\rho(1+\sigma)(1-2\sigma)}} \quad (3)$$

Where Y is the Young modulus and σ is the Poisson's ratio.

The classical engineering trade-off of diagnostic ultrasound instrumentation is that between resolution and the depth of the image. Both are directly affected by the ultrasonic frequency and attenuation. As frequency is increased, resolution improves and penetration decreases. Resolution improves because the ultrasonic wavelength in tissues decreases [8].

The passage of ultrasound through tissue causes local heating. Absorption of the energy of longitudinal elastic compression waves by the tissue at various interface through which the sound passes results in an increase in the temperature of the irradiated tissue by an amount which is dependent on the ultrasound frequency, the mean intensity, the total time of irradiation and thermal characteristics of the system [9]. If a liquid is exposed to intense sonic vibrations, small gases are formed within it. Ultrasound waves produce mechanical disturbance which consist of positive pressure fluctuations above and below the pressure of the liquid in which they travel. A reduction in pressure encourages sub-microscopic bubbles to grow while a pressure above that of the liquid will cause collapse of the bubble and this phenomenon is known as cavitations [10]. Here, tiny bubbles grow into larger bubble and then collapse. This can create hazardous free radicals such as OH^-. Cavitation can incur to tissue damage and cell destruction [11].

Apfel and Holland [12] have shown that the potential for the onset of inertial cavitation is proportional to a 'mechanical index' (MI) give by

$$MI=\frac{P_r}{\sqrt{f}} \quad (4)$$

Where P_r is the negative pressure and f is the frequency [11].

Intensity and acoustic power levels from diagnostic ultrasound machines in developing countries including Nigeria are not usually measured due to lack of competent in-house Hospital/ medical Physicist and calibrated ultrasound power meters. This work will therefore determine the intensity and acoustic power levels from the diagnostic ultrasound machine at General Hospital Gboko using ultrasound power meter UPM-DT-10AV obtained from Ohmic instruments in USA. This will provide means of monitoring intensity levels from the diagnostic ultrasound machine and will assist in keeping patients radiation exposures to minimum levels [13].

2.0 Materials and Methods

In this work, the ultrasound power meter, model UPM-DT-10AV was used in carry out measurements on the diagnostic ultrasound machines (scanning machines) located at General Hospital Gboko. The principle of measurement is the radiant force method. The UPM-DT-10AV uses a positioning clamp to hold the transducer in de-gas water above a conical target. The ultrasonic energy passes through the water to reflect off the target and is then absorbed by the rubber lining. The radiant power is directly proportional to the total downward force (weight) on the target. This weight is then transferred through the target support assembly to the electro-mechanical load cell inside the scale. The cell is in a computer-controlled feedback loop and produces a digital readout in Watts of grams of force. The ultrasound scanning machine at General Hospital Gboko has machine model SI-500 with display modes B,BB,BM and M modes manufactured by Siemens Medical systems Germany.

3.0 Results and Discussion

The results of the average acoustic power (W) and average intensity levels (W/cm^2) are presented in Table 1 and Fig. 1 respectively.

From the results shown in Table 1, the average acoustic power (W) at the Hospital ranges from 1.82 $\pm$ 0.51 W to 14.94 $\pm$ 0.44 W and 1.90 $\pm$ 0.34 W to 15.46 $\pm$ 0.42 W for the pulse and continuous wave propagation modes respectively. While the average intensity (W/cm^2) ranges from 0.04 $\pm$ 0.01 W/cm^2 to 0.29 $\pm$ 0.01 W/cm^2 and 0.04 $\pm$ 0.01 W/cm^2 to 0.30 $\pm$ 0.01 W/cm^2 obtained from the diagnostic ultrasound machine during the minimum exposure period of 3 minutes is seen to be within the maximum allowable intensity limits of 0.72 W/cm^2 and 0.43 W/cm^2 for scanning of the peripheral vessels and cardiac scan and 0.094 W/cm^2 for fetal and others* scan (others*include abdominal, intra-operative, pediatric, breast, thyroid and testes) FDA [14] and WFUMB [15]. Although these values can be seen to exceed the maximum allowable intensity limits of 0.017 W/cm^2 for ophthalmic scan, it is within the allowable limits for other applications like cardiac and fetal scans.

Table 1: Measured ultrasound output parameter at General Hospital Gboko

S/N	Time (minutes)	Average Acoustic Power (W)		Average intensity (I_{av}) (W/cm^2)	
		PW	CW	PW	CW
1	3.00	1.82± 0.51	1.90± 0.44	0.04± 0.01	0.04± 0.01
2	6.00	2.06± 0.36	2.86± 0.45	0.04± 0.01	0.05± 0.01
3	9.00	3.44± 0.56	3.92± 0.46	0.07± 0.02	0.08± 0.01
4	12.00	5.20± 0.42	5.32± 0.51	0.10± 0.01	0.10± 0.01
5	15.00	5.98± 0.52	6.42± 0.52	0.11± 0.02	0.12± 0.02
6	18.00	6.84± 0.44	7.86± 0.56	0.13± 0.01	0.15± 0.02
7	21.00	8.36± 0.56	9.03± 0.68	0.16± 0.02	0.17± 0.02
8	24.00	9.64± 0.66	9.88± 0.48	0.18± 0.02	0.19± 0.01
9	27.00	12.28± 0.82	13.24± 0.44	0.23± 0.02	0.25± 0.01
10	30.00	14.94± 0.44	15.46± 0.42	0.29± 0.01	0.30± 0.01

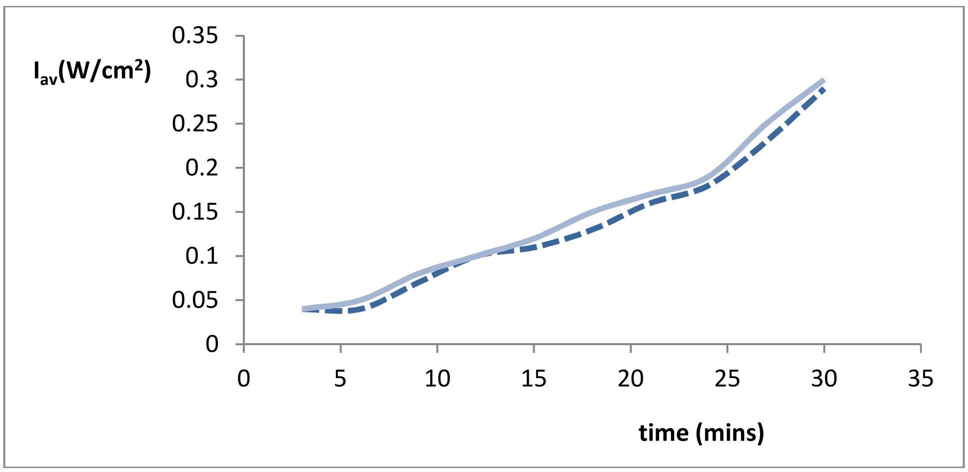

Fig. 1 A graph average Intensity against Time at General Hospital Gboko

Note:

------- = pulse wave (PW) propagation

________ = continuous wave (CW) propagation

As the exposure duration increases radiation intensity levels also increases gradually in an exponential manner to a maximum average value of 0.29 ± 0.01 W/cm^2 and 0.30 ± 0.01 W/cm^2 for pulse and continuous wave propagation mode respectively at a measured time duration of 30 minutes. Thus at this maximum average intensity values, the ultrasound machine is seen to be within the safety limits of 0.72 W/cm^2 and 0.43 W/cm^2 for the scanning of peripheral vessels and cardiac scan respectively FDA [14] and [15]. The maximum average intensity values are beyond the maximum allowable limits of 0.017 W/cm^2 and 0.094 W/cm^2 for ophthalmic scan, fetal and others* scan. From the results, the values continuous wave propagation mode are slightly higher than the pulse wave propagation mode and this is because when ultrasound is transmitted in pulse wave form, the acoustic intensity is high during the pulse and zero during the period between pulses [16]. Also it should be noted that continuous wave propagation are rarely used in clinical setting [17] most commonly, continuous wave equipment is used without concurrent real time imaging facilities and its use in obstetrics is therefore limited to acquiring wave forms from the umbilical artery and the uteroplacental vessels.

4.0 Conclusion

The measured average acoustic out-puts from the diagnostic ultrasound machine located at General Hospital Gboko has shown that for safety reasons it is clinically advisable to use the machine for the scanning of only peripheral vessels and cardiac scan since it minimum measured average intensity values and fall within the allowable maximum safety limits of 0.72 W/cm^2 and 0.43 W/cm^2 for scanning of peripheral vessels and cardiac scan. For other clinical applications like ophthalmic scan, fetal and others* scan, the diagnostic ultrasound machine should not be used on a particular patient organ beyond 9 minutes. Thus this work has shown that some Hospitals and Clinics may have ultrasound machines with output intensities beyond the maximum safety limits of 0.43 W/cm^2, 0.72 W/cm^2, 0.094 W/cm^2 and 0.017 W/cm^2 as recommended by WFUMB [15] and FDA [14].

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