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Determination of Acoustic Power and Intensity Levels from Diagnostic Ultrasound Machines

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ABSTRACT

The average acoustic power and intensity levels from diagnostic ultrasound machines at five major Hospitals in Benue State were measured using ultrasound power meter UPM-DT-10AV. The ultrasound machine at Christian Hospital Mkar, Immaculate Conception Hospital Makurdi, Federal Medical centre Makurdi, Myom Hospital Gboko and Lobi Specialist Hospital Makurdi were used for the research work. The ultrasound power meter measures the out-put acoustic power from the ultrasound beams which were converted to intensity level, three set of readings were taken for each of the pre-timed duration of 5,10,15,20 and 25 minutes, the average values were then found. The results shows that the acoustic power and intensity levels from the measured ultrasound machines were not stable over time and that the intensity level increases exponentially with increase in the scanning duration. From the measured acoustic outputs, it was seen that the diagnostic ultrasound machine model EMP-860 located at Lobi Specialist Hospital Makurdi has the highest average intensity value of 0.51±0.01W/cm^2 for an exposed duration of 25 minutes and a minimum value of 0.06±0.003 W/cm^2 for an exposed duration of 5 minutes while the diagnostic ultrasound machine model SonoAce 8000 located at Federal Medical Centre Makurdi has the lowest measured average intensity value of 0.0067±0.0009 W/cm^2 and higher intensity value of 0.099±0.0012 W/cm^2 at an exposed duration of 5 and 25 minutes respectively. This work aims will assess ultrasound dosimetry compliance in our Hospitals and provides database for diagnostic ultrasound quality control in Benue State and Nigeria. The work has shown that some of the ultrasound machines have output intensities beyond the maximum safety limit of 0.094 W/cm^2 as recommended by WFUMB (1998) and FDA (1993) for fetal and abdominal scan.

Keywords: *Intensity levels, Diagnostic ultrasound, Potential bioeffect, Acoustic power*

I. INTRODUCTION

Ultrasound imaging has been in use over three decades, the use of ultrasonic imaging as a diagnostic tool has increase considerable. Acoustic output of machines has also increased; in some cases it can have some potential hazards. The two damage mechanisms are heating and cavitation. Other potential mechanisms are mechanical forces such as bulk acoustic streaming and standing wave radiation forces [1].

Thus ultrasound exposure measurements on medical ultrasonic systems are essential as regards aspects of safety and quality assurance [2]. Determining the acoustic output of medical devices is essential for manufacturers to demonstrate standards compliance, this is also important in prototype evaluation and type testing [3]. With the increasing use of ultrasound on human tissue and the potential hazardous effect of sonication, there is need to define more precisely the threshold intensity for the observed or suspected effects of ultrasound, especially in the relation to diagnostic and therapeutic ultrasound [4].

Ultrasound devices can be calibrated by the measurements of power and intensity levels using an ultrasound power meter model UPM-DT-10AV which employs radiation force balance method. Measured values are than compared with standard set in the United States and Canada by the International Electrotechnical Commission (IEC) [5], the FDA and American Institute of Ultrasound in Medicine [6].

Acoustic output can also be measured using calorimetric method as described by Wells et al [7]. this method involves the use of the electrical power in a heating element needed to get the same heating rate as that produced by the sound beam is determined and the magnitude of the power input to the heating element is taken as equivalent to the acoustic power emitted by the sound source. A thermo acoustic measurement technique based on the transformation of the incident ultrasound energy into heat inside a cylindrical absorber can be performed using calorimetric method [2]. Radiation pressure method have for some time been considered as acceptable in absolute intensity determination. When sound waves pass through a fluid, the resulting sound waves has a steady component which is the radiation pressure (P_{rad}) give rise to a force at the interface between media of different acoustic impedances, and it is equal in magnitude to the energy density in the beam. Thus, the product of P_{rad} and the propagation velocity C gives the sound intensity, I, i.e.

$$\textbf{Intensity, } I = P_{rad}\, C = \frac{F}{A} C$$

Where F is the net force exerted by the incident sound beam and A is the area of cross-section of the beam. Thus, the sound intensity can be obtained if F and A are measured and C is known [4].

Measurement of power output levels of diagnostic and therapeutic ultrasound equipment has become increasingly important to determine exact patient exposure levels in case a potential risk exists to the patient. Since the Radiation control for Health and Safety Act of 1968 and the 1976 Medical

Device Amendments to the FDA (USA) Act became effective, all manufacturers of diagnostic Doppler ultrasound equipment are required to submit information regarding their maximum peak and average exposure level, beam patterns, and other pertinent information. Hospitals are responsible for regularly scheduled testing (every six months) of output power and safety to maintain their accreditation [8]. Intensity and power density levels from diagnostic ultra sound machines in developing countries including Nigeria are not usually measured due to lack of competent in-house Hospitals/Medical physicist and calibrated ultra-sound power meters. This work will therefore determine the intensity and power density levels from diagnostic ultra-sound machines in some selected hospitals using ultra-sound power meters UPM –DT-10AV obtained from Ohmic Instrument in USA. This will provide a means of monitoring intensity levels from diagnostic ultra-sound machines and will assist in keeping patients radiation exposures to minimum levels from the diagnostic machines.

II. MATERIALS AND METHODS

In this research work, the ultrasound Power Meter, Model UPM-DT-10AV, was used in carrying out measurements on diagnostic ultrasound machines (Scanning machine) in the various hospitals visited. The power meter is designed to measure the ultrasound power output of diagnostic or therapeutic transducers up to 30 watts with an operating frequency of .5-10 MHZ. The principle of measurement is the radiant force method. The UPM-DT-10AV uses a positioning clamp to hold the transducer in de-gassed 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 propositional to the total downward force (weight) on the target. This weight is then transferred through the target support assembly to the electro-produces a digital readout in watts of power (custom units) or grams of force.

The power meter comes complete with all accessories (clamp assembly, cone assembly, power supply, and tank). The principle of measurement is the radiant force method. The meter uses a positioning clamp to hold the transducer in de-gassed 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 radiated power is directly propositional 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 power or grams of force [8]. Also the ultrasound machines use in some major Hospitals were used to carry-out measurements and verifications of the inclusion of potential risk index on the display screen of the machines manufactured after 1992 [9]. It is important to measure ultrasound power level to verify correct patient exposure and reduce potential risks.

Five ultrasound scanning located in five hospitals in Benue State were used. The hospitals were; Christian Hospital Mkar, Immaculate conception Hospital Makurdi, Federal Medical Center Makurdi, Myom Hospital Gboko and Lobi Hospital Makurdi. The Scanning machines are all situated at the Scanning unit of the hospitals. The diagnostic ultrasound machine located at Christian Hospital Mkar has the following technical specifications; **model:** BU-907; **manufacturers:** Guangzhou Yao-Yuan industries co; ltd china; **S/N:** AJ 1190281; **display mode:** B mode ultrasound diagnostic equipment; **power:** 100-240v, **safety:** class 1- type B; **maximum power (mW):** maximum temporal-average power IEC 611574.2.2a; **out- put beam intensity:**16.09 cm^2; **area of the probe:** $15mm\times10mm=150mm^2 =15cm^2$. The diagnostic ultrasound machine located at Immaculate Conception Hospital Makurdi has the following technical specification; **model:** Siemens prima model C3-7ED; **manufacturer:** Sonosite Inc. USA; **S/N:**D0280762; **display mode:** B and B/M; **power:** 100-240v; **pulse frequency:** 60 Hz; **out-put power:** 0-3 w/cm^2; **area of the probe:** $17mm\times10mm= 170mm =17cm^2$. The diagnostic ultrasound machine located at Federal medical center Makurdi has the following technical specification; **model:** Medison SonoAce 8000; **manufacturer:** Medison Accuvix USA; **S/N:** C3-7ED; **imaging mode:** B, B/B, B/M, M-Dead; **power:** 120-240v; **pulse frequency:** 60 Hz; **3d function:** optional; **area of the probe:** $15mm\times10mm=150mm^2=15cm^2$ while the intra cavity probe has an area of $8mm\times6mm=48mm^2=4.8cm^2$. The diagnostic ultrasound machine located at Myom Hospital Gboko has the following technical specification; **model:** SI-400 ultrasound imaging system; **manufacturer:** Siemens Medical Systems, Inc. Issaquah, WA 950277002, Germany; **Imaging mode:** B-mode and M-mode; **maximum power (mW):** 70 for B-mode and 96 for m-mode; **out-put beam dimensions (mm):**14, 4×13; **Scanning width:** 94-101 mm; **area of the probe:**$15mm\times13mm=195mm^2=19.5cm^2$. The diagnostic ultrasound machine located at Lobi Specialist Hospital has the following technical specification; **model:** EMP- 860; **manufacturer:** Shenzhen Emperor Electronic Technology Co. LTD China; **imaging mode:** B,BB,BM, and M; **SN:** 17780601; **device power:** 115 VA; **pulse frequency:** 50 HZ; **area of the probe:**$18mm\times12mm=216mm^2=21.6cm^2$. Degassed water was used in order to minimize micro bubbles which could cause multiple reflections of the ultrasound waves thus giving rise to erroneous power or intensity values.

III. RESULTS AND DISCUSSION

All the results of the experimental procedures carried at Christian Hospital Mkar, Gboko; Immaculate conception Hospital, Makurdi; Federal Medical Center, Makurdi; Myom Hospital Gboko and Lobi specialist Hospital, Makurdi are presented in tables 1.1, 1.2, 1.3, 1.4 and 1.5 respectively.

Table 1.1: Measured Ultrasound Output Parameters at Christian Hospital Mkar, Gboko

S/N	Time (mins)	Averaged power (W)	Averaged intensity (I_{av}) (W/cm^2)
1	5.00	9.72±0.36	0.18±0.02
2	10.00	14.74±0.93	0.28±0.02
3	15.00	16.34±0.61	0.31±0.01
4	20.00	18.03±0.97	0.34±0.02
5	25.00	22.51±0.46	0.43±0.01

Table 1.2: Measure Ultrasound Output Parameters at Immaculate Conception Hospital Makurdi

S/N	Time (mins)	Average acoustic power (W)	Average intensity (I_{av}) (W/cm^2)
1	5.00	2.27±0.71	0.04±0.01
2	10.00	4.52±0.92	0.08±0.02
3	15.00	7.41±0.56	0.14±0.0.01
4	20.00	9.37±0.71	0.18±0.01
5	25.00	13.94±0.44	0.26±0.01

Table 1.3: Measure Ultrasound output Parameters at Federal Medical Centre Makurdi

S/N	Time (mins)	Average Acoustic power (W)		Average intensity (I_{av}) (W/cm^2)	
		PW	CW	PW	CW
1	5.00	0.35±0.05	0.53±0.06	6.69x10^{-3}±0.88x10^{-3}	10.03x10^{-3}±1.07x10^{-3}
2	10.00	0.51±0.03	0.70±0.07	9.72x10^{-3}±0.51x10^{-3}	13.31x10^{-3}±1.26x10^{-3}
3	15.00	1.22±0.19	1.51±0.10	23.10x10^{-3}±3.53x10^{-3}	28.52x10^{-3}±1.83x10^{-3}
4	20.00	2.18±0.18	2.26±0.17	41.33x10^{-3}±3.47x10^{-3}	42.72x10^{-3}±3.22x10^{-3}
5	25.00	5.21±0.61	6.13±050	98.57x10^{-3}±11.61x10^{-3}	116.12x10^{-3}±9.58x10^{-3}

Table 1.4: Measure Ultrasound Output Parameters at Myom Hospital Gboko

S/N	Time (mins)	Average Acoustic Power (W)	Average intensity (I_{av}) (W/cm^2)
1	5.00	3.81±0.09	0.07±0.00
2	10.00	4.99±0.26	0.10±3.33x10^{-3}
3	15.00	5.55±0.22	0.10±3.33x10^{-3}
4	20.00	6.79±0.27	0.13±6.67x10^{-3}
5	25.00	10.01±0.15	0.19±0.01

Table 1.5: Measure Ultrasound Output Parameters at Lobi Specialist Hospital Makurdi

S/N	Time (mins)	Average Acoustic Power (W)	Average intensity (I_{av}) (W/cm^2)
1	5.00	2.94±0.29	0.06±3.33x10^{-3}
2	10.00	10.91±0.24	0.21±3.33x10^{-3}
3	15.00	14.85±0.41	0.28±6.67x10^{-3}
4	20.00	18.85±0.17	0.36±3.33x10^{-3}
5	25.00	27.19±0.48	0.51±0.01

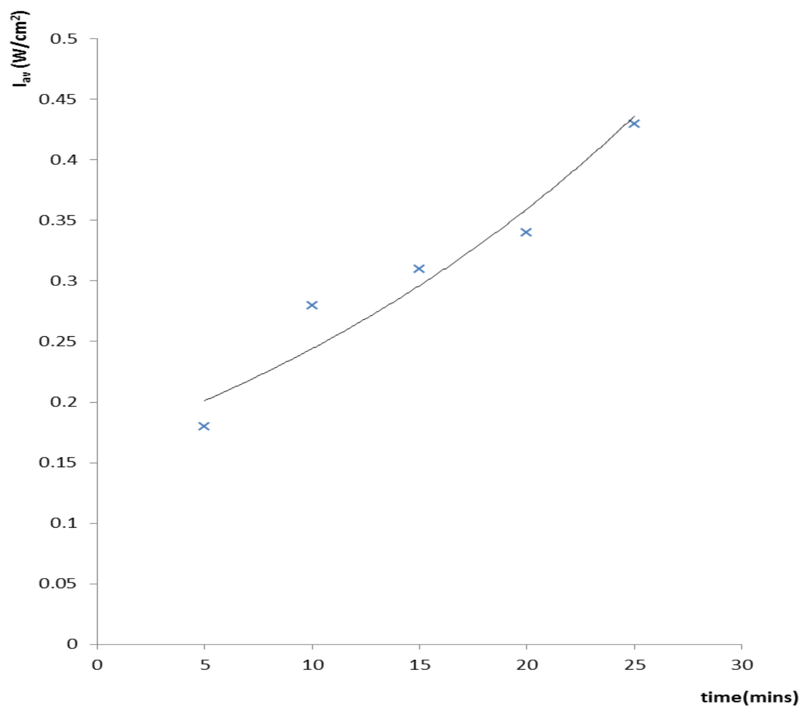

Fig. 1.1: A graph of I_{av} against Time for readings at Christian Hospital Mkar, Gboko

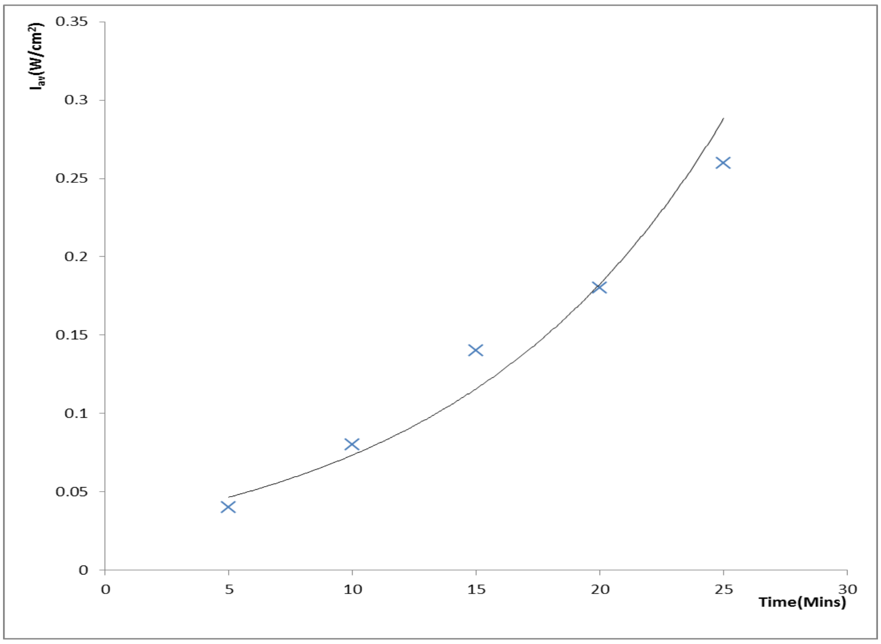

Fig. 1.2: A graph of I_{av} against Time for readings at Immaculate Conception Hospital Makurdi

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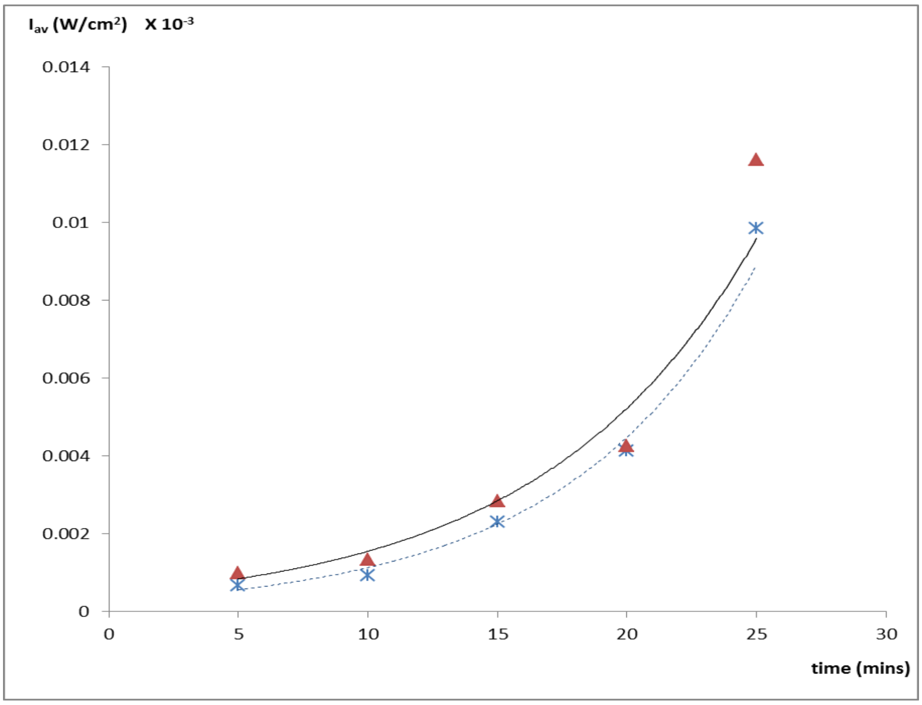

Fig. 1.3: A graph of I_{av} against Time for reading at Federal Medical Center, Makurdi

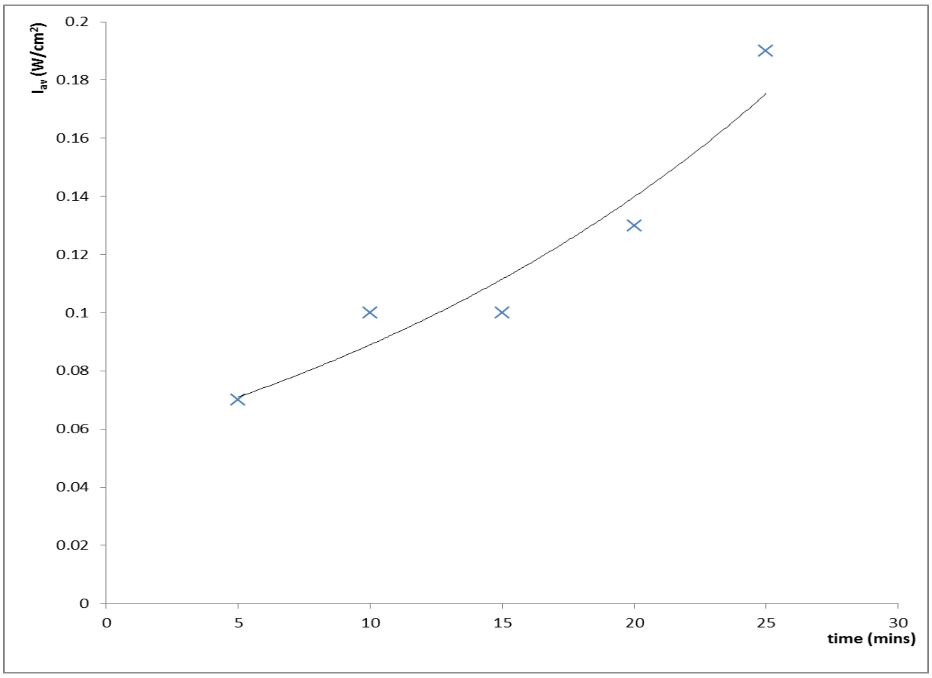

Fig. 1.4: A graph of I_{av} against Time for Readings at Myom Hospital, Gboko

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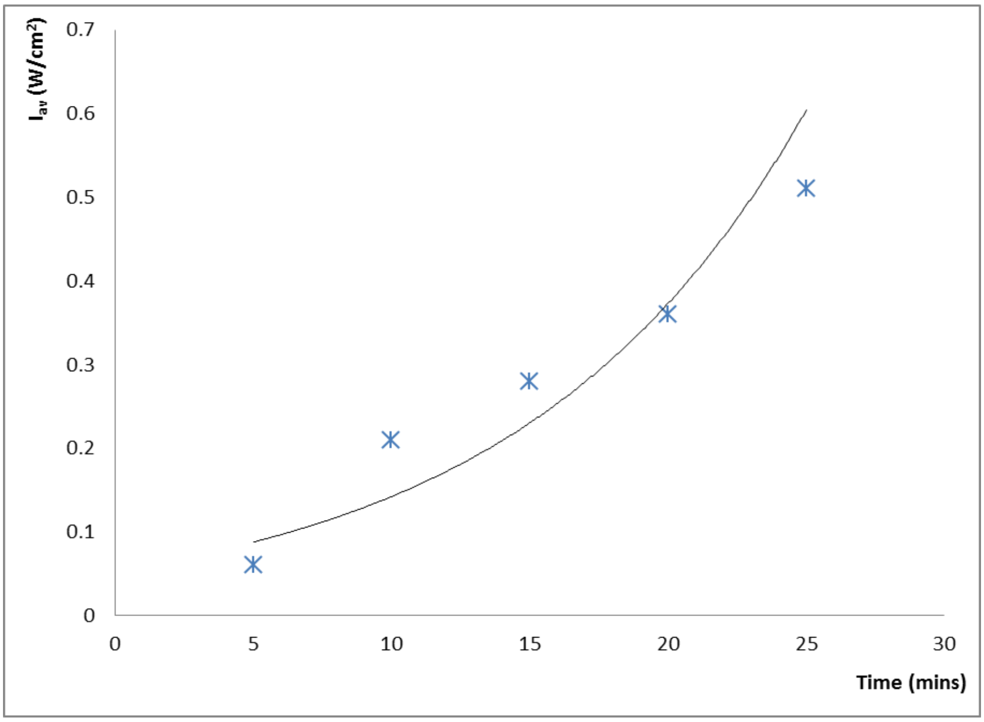

Fig.1.5: A graph of I_{av} against Time for readings at Lobi Specialist Hospital Makurdi

The result of the acoustic power (w) and averaged intensity levels (w/cm^2) obtained from the diagnostic ultrasound machines for the various hospitals are shown in table 1.1, 1.2, 1.3, 1.4 and 1.5 respectively. From the results shown in table 1.1, the averaged acoustic power (w) measured from the diagnostic ultrasound machine located at Christian Hospital Mkar ranges from 9.72±0.36w to 22.51±0.40w with a calculated averaged intensity ranging from 0.18±0.01w/cm^2 to 0.43±0.01, the minimum averaged intensity value of 0.18±0.01w/cm^2 obtained as a result of continuous irradiation of ultrasound beams for a period of 5 minutes is below the recommend maximum values of 0.43w/cm^2 and 0.72w/cm^2 set by WFUMB [10] and FDA [11] for the scanning of the cardiac and peripheral vessels but slightly above the recommended maximum value of 0.094 W/cm^2 for fetal and abdominal scan, while the averaged maximum intensity value of 0.43 ± 0.01W/cm^2 obtained from continuous irradiation of ultrasound beams for a period of 25 minutes is above the recommended maximum values of 0.043 W/cm^2 and 0.094W/cm^2 for cardiac and fetal scanning but below the recommended value for scanning of the peripheral vessel. Thus the ultrasound machine from this Hospital is likely a source of potential bioeffect if used on a patient for fetal and abdominal scans for time duration of more than 5 minutes as the intensity level from such exposed time is above the recommended maximum value of 0.094 W/cm^2 [12].

The plotted graph of fig. 1.1 from the data of table 1.1 shows an exponential line graph of measured average intensity as a function of time. The linear increase in intensity as the scanning duration increases can be seen to be in agreement with the work of Jago *et al* [13], which that the ultrasonic intensity level increase with increase in scanning time. The work by Whittinghan, [14] also shows that actual temperature rise in exposed tissue will depend on the local specific heat capacity and time of exposure. It will also depend on the rate of temperature rise and distribution of heat in neighboring tissues, parameter of this is known as the perfusion length given by $L = \sqrt{(K/WS_b)}$ Where K is the thermal conductivity of the tissue, W is the blood perfusion flow rate and S_b is the specific heat capacity of blood [12]. The lengthy exposure of scanning tissue to ultrasonic beans with subsequent rise in temperature is termed the thermal index (TI) bioeffect which is dependent on the exposure time and raise in cells temperature [13].

The result in table 1.2 also shows the averaged measured values of acoustic power in watts and the intensity levels in watts per cm^2 of the diagnostic machine from Immaculate Conception Hospital Makurdi. The acoustic output from the diagnostic ultrasound machine ranges from 2.27 ± 0.71 W to 13.94 ± 0.44 W with the averaged intensity ranging from 0.04 ± 0.01 W/cm^2 to 0.26 ± 0.01 W/cm^2 at a measured time duration of 5 minutes and 25 minutes respectively. The minimum measured average intensity of 0.04 ± 0.01 W/cm^2 is within the acceptable recommended maximum value set by the FDA [11] and WFUMB [10] for scanning of the cardiac, peripheral vessel and fetal scan which have recommended maximum values of 0.43 W/cm^2, 0.72W/cm^2 and 0.094 W/cm^2 respectively while the maximum measured value of 0.26 ± 0.01 W/cm^2 is only within the maximum recommended values for scanning of the cardiac and peripheral vessel and the value is beyond the maximum set standard for fetal scanning. The resultant graph of fig. 1.2, which is a plot of measured averaged intensity against time, also shows an exponential increase in intensity as the scanning time increases.

The result of table 1.3 similarly shows the measured average acoustic power in watts and intensity level in watts per cm^2 from the diagnostic ultrasound machine located at Federal Medical Centre Makurdi. The result shows that acoustic power output ranges from 0.35 ± 0.05 W to 5.21 ± 0.61 W for pulse wave acoustic transmission and 0.35 ± 0.06 W to 6.13 ± 0.50 W for continuous wave acoustic transmission mode. The values of the pulse wave transmission can be seen to be slightly less than that of continuous wave; this is because when ultrasound is transmitted in a pulse wave form, the acoustic intensity is high during the pulse and zero during the period between pulses [15]. The result also shows the values of the averaged intensity ranging from 0.0067 ± 0.0009 W/cm^2 to 0.099 ± 0.0012 W/cm^2 for the continuous wave transmission mode. The graph of fig. 1.3 for the measured averaged intensity against time also shows an exponential increase in intensity as the scanning duration increases, which is in agreement with the work of Jago *et al* [13]. Both the maximum and minimum measured values of the averaged intensity from the diagnostic ultrasound machine at Federal Medical Centre Makurdi obtained at a scanning duration of 25 and 5 minutes respectively can be seen to be within the recommended maximum safety values of 0.094 W/cm^2 and 0.72 W/cm^2 for fetal scanning and scanning of the peripheral vessels [12].

The results of table 1.4 for the measured averaged acoustic power in watts and averaged intensity in watts per cm^2 at Myom Hospital Gboko shows the acoustic power ranging from 3.81 ± 0.09 W to 10.01 ± 0.15 W for a scanning duration of 5 and 25 minutes respectively. Also the averaged intensity ranges from 0.07 ± 0.00 W/cm^2 to 0.19 ± 0.01 W/cm^2, thus the minimum value of 0.07 ± 0.00 W/cm^2 obtained from continuous scanning for 5 minutes is within the safe scanning limit recommended by WFUMB,[10] for fetal scanning while the maximum intensity value of 0.19 ± 0.01 W/cm^2 obtained by continuous scanning for 25 minutes is beyond the maximum safe values recommended for fetal scanning, but the value can be seen to be within the maximum recommended safe limit of 0.43 W/cm^2 and 0.72 W/cm^2 for Scanning of the cardiac and peripheral vessels [14].

Last but not the least is the results of table 1.5 which shows the values of measured averaged acoustic power in watts and intensity levels in Watts per cm^2 for Measurements at Lobi Specialist Hospital Makurdi. The result shows the acoustic power ranging from 2.94 ± 0.29 W to 27.19 ± 0.48 W at measured time duration of 5 minutes and 25 minutes respectively. Also the averaged intensity ranges from 0.06 ± 0.003 W/cm^2 to 0.51 ± 0.01 W/cm^2, the minimum intensity value of 0.006 ± 0.003 W/cm^2 which is a result of continuous scanning for 5 minutes is within the maximum recommended safe standard of 0.094 W/cm^2, 0.43 W/cm^2 and 0.72 W/cm^2 for fetal scanning, Cardiac and peripheral vessel [8].

IV. CONCLUSION

This work is a pioneering research in the area of diagnostic ultrasound dosimetry assessment and compliance in Hospitals located in the Benue State and Nigeria. The work has established that different diagnostic ultrasound machines have varied beam intensity levels as measured within the same scanning duration. The research has shown that some of the ultrasound machines have output intensities beyond the maximum safety limit of 0.72 W/cm^2 and 0.094 W/cm^2 as recommended by WFUMB [10] and FDA [11] for the scanning of cardiac and peripheral vessel, and also for fetal and abdominal scan.

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