In group A the results of two children had to be excluded because they were unable to carry out the tests correctly. One group B child refused to take the tests, whilst a second child's results had to be excluded due to a mechanical fault. Thirteen sets of lung function tests in each group were thus available for analysis. For each child, the results were correlated with his or her age, weight and height and calculated as a percentage of the predicted values according to Schoenburg.

Table 2 compares the average values for the two groups. Graphical representation of the average percentage values reveals no significant differences in lung function between the two groups (Figure 1). In both groups, however, the FEV1, FEV1% and FEF50 are lower than the normal average of 100% predicted by Schoenburg. Only the FVC in both groups and the PEFR in group B reached normal values.

DISCUSSION AND CONCLUSIONS

The higher reported incidence of respiratory disease in group B children, who lived closer to the petrochemical complex, cannot be regarded as statistically significant due to the small sample size. The higher incidence of smokers in group B parents may also have played a role in the higher incidence of disease in this group. Although no correlation was found between the number of smokers in the house and the number of children who suffered from asthma, a previous study has shown that children's lung functions are adversely affected when their parents, and in particular their mothers, smoke. However, a study carried out in Ohio also showed a higher reported incidence of acute and chronic respiratory disease in children attending school in an area of raised SO2 and NO2 levels.

No significant difference could be found between the lung functions of the two groups of children, but both groups demonstrated lower values than the predicted norms. Since the possibility of a degree of air pollution in the area of the control group could not be excluded, a further study of a larger sample of children from suburbs bordering on the petrochemical complex is recommended, with a control group from further afield. Although the 1986 CSIR study of the area showed pollution at that time to be within acceptable limits, Mostardi has suggested that the acceptable limits for atmospheric SO2 and NO2 should be redefined.

Acknowledgements

Thanks are recorded to Professor MA de Kock, former Head of the Department of Internal Medicine, University of Stellenbosch, for the provision of the ELF and for training in its use, and also to Dr S Walsh of the same Department for help in analysing the results.

REFERENCES


CHARACTERIZATION OF THE ACOUSTIC OUTPUT OF THERAPEUTIC ULTRASOUND EQUIPMENT

M G van der Merwe (MSc Physics Stellenbosch)
N Bhagwandin (MSc Physics Natal)
J E van der Spuy B Eng Hans Stellenbosch)
P R le Roux (PhD Physics Cape Town).
Directorate of Radiation Control

SUMMARY

The safety and efficacy of ultrasound therapy may be compromised if the output from therapy transducers differs considerably from the indicated value. Although the total power output of a transducer can be easily measured using a pressure balance, it is also important to know how this energy is distributed through space. By using a hydrophone scanning technique, beam profiles of the energy distribution can be obtained. From the beam profiles various parameters such as the effective radiating area (ERA) and the beam non-uniformity ratio (BNR) can be determined. Since the spatial-average intensity selected for treatment is a ratio of the emitted ultrasound power and the effective radiating area, it is essential to be able to measure parameters like the effective radiating area. In this study ERA and BNR measurements for commercially available devices were performed with a hydrophone scanning technique.

OPSOMMING

Die effektiewe area (ERA) en die nie-uniformiteitsverhouding van die ultrakorte metode terent kry gekry of om te weet hoe die energie ruimtelik versprei word. Aangesien die ruimtelik-gemiddelde intensiteit, wat gewoonlik deur gebruikers van die entrelasingsarea (ESA) en die nie-uniformiteitsverhouding van die binedel (BNV) gekyk word, is dit van belang om parameters soos die effektiewe entrelasingsarea te bepaal. In hierdie studie is gebruik gemaak van die ELF en BNV wetenskaplike toestelle te verkry.

DEFINITIONS

Effective radiating area (ERA) means the area of the effective radiating surface that consists of all points at which the ultrasonic...
intensity is equal to or greater than 5% of the maximum spatial ultrasonic intensity at the effective radiating surface, expressed in cm$^2$.

Beam non-uniformity ratio (BNR) means the ratio of the highest intensity (spatial peak) in the ultrasound field to the average intensity.

**INTRODUCTION**

Of all the techniques available to measure and characterize the acoustic output of ultrasound therapy equipment, the determination of total power with a radiation pressure balance together with the spatial and temporal field characterization using a calibrated hydrophone have found most widespread use and acceptance. These two techniques permit the measurement of most parameters accepted to be of importance in ultrasound therapy applications.

The principle of the radiation pressure balance is the measurement of the force produced on a target intercepting the whole ultrasound beam. The force may be related to the total power in the ultrasound beam. Various designs of ultrasonic pressure balances are widely used to assess the accuracy of the total output power of ultrasound therapy devices.

However, major shortcoming in the use of pressure balances is the fact that no information is gained on the distribution of ultrasound throughout the acoustic field. The determination of the distribution of acoustic energy in both space and time is important in the assessment of parameters like the effective radiating area and the beam non-uniformity ratio. For the measurement of these parameters a beam plot system is used. In essence, the system consists of a water tank into which the ultrasound beam radiates and a calibrated measuring hydrophone (underwater microphone) scanning the beam by mechanical means.

A hydrophone is a device that produces an electrical signal in response to an applied acoustic field. The sensitive element of the hydrophone is usually a small piezoelectric element and the electrical voltage developed is related to the acoustic pressure at the element. By scanning a hydrophone across an ultrasound field, an indication of the distribution of the acoustic pressure across the field can be obtained (a beam profile). In this study these beam profiles are used to determine:

- The Effective Radiating Area (ERA); and
- The Beam Non-uniformity Ratio (BNR).

**MEASUREMENT APPARATUS**

![Figure 1: Schematic and block diagram of the measurement apparatus](image)

The measurement apparatus at the Directorate Radiation Control is shown schematically in Fig. 1. The ultrasound scans are done in a tank, 60 x 26 x 26 cm to which fixtures are attached for mounting hydrophones and transducers. The hydrophone mount is attached to a gear system which provides x, y and z translation. The hydrophone can also be rotated about two axes. Scans used for measurements consist of a two-dimensional array of data accumulated in a raster fashion in the x,y plane, at a fixed z-distance from the transducer face. The scan size and step size are variable. Typical step sizes are between 1 mm and 2 mm and typical scans consist of approximately 2000 data points.

All measurements are made in tap water with a nominal 0.5 mm diameter Medisonics (Medisonics (UK) Ltd., Haslemere, Surrey, UK) hydrophone, which has a frequency range between 200 kHz and 15 MHz.

**RESULTS**

Effective Radiating Area (ERA)

The measurement of the effective radiating area (ERA) of ultrasonic physiotherapy devices is a crucial facet of their calibration. The spatial averaged intensity, formulated as the ratio of the ultrasonic power to the effective radiating area (ERA), is one of the fundamental treatment parameters chosen in ultrasound therapy. Temperature rises in tissue, which play a considerable role in ultrasound therapy, are proportional to this quantity. The intensity levels for therapy are also in the range where adverse biological effects have been observed. Problems can therefore arise with both the safety and efficacy of treatments if the spatial average intensities deviate considerably from their indicated values.

Some of the difficulties encountered with ERA measurements have been discussed elsewhere. A sample plot of a two-dimensional raster scan, obtained with the hydrophone scanning technique to determine the ERA, is shown in Fig. 2.

![Figure 2: Sample plot in near field (5mm from transducer face)](image)

**Beam Non-uniformity Ratio (BNR)**

The ultrasonic beam distribution produced by a therapeutic transducer is nonuniform in nature. The intensity within the ultrasonic beam varies; that is, some points are higher or lower than others. Thus, when an ultrasonic therapy unit is set to produce a particular intensity, say 2 W/cm$^2$, there will be places in the beam where the intensity is actually higher than the indicated value. A numerical indicator of this non-uniformity is provided by the beam non-uniformity ratio, abbreviated BNR.

![Figure 3: Sample plot to determine the BNR](image)

The BNR is simply the quotient of the highest intensity in the field to the average intensity indicated on the meter. For example, if the
Science to support the

Boehringer Ingelheim nebulising solutions
New — Atrovent Inhalant Solution

Unit Dose Vials

- Added always to your standard β₂ solution
- Precise dose every time
- Simple and convenient
- Preservative-free

Bisolvon® solution

- Reduces bronchial and nasal secretion viscosity
- Facilitates mucociliary transport and expectoration

Boehringer Ingelheim Inhalation Therapy

Creating a better climate for your patients
BNR is 4.0 and the unit is set for an indicated intensity of 2.0 W/cm², then at some point in the beam the intensity is actually 8.0 W/cm². By looking at the intensity distribution of an ultrasound beam, some qualitative information about where the highest intensity is located can be acquired. The BNR is a useful indicator of the degree of non-uniformity. It is therefore vital in the therapeutic application of ultrasound that the applicator (soundhead) be moved continuously over the area being treated as a result of non-uniformity of the beam. This causes the energy distribution to be more uniform and thus prevents high temperature buildup in tissues. A sample plot of a two-dimensional raster scan, obtained with the hydrophone scanning technique to determine the BNR, is shown in Fig. 3.

DISCUSSION

Measurements were made on 6 ultrasonic beams, one from each commercially available ultrasonic physiotherapy device inspected. It is recommended that the measured effective radiating area (ERA) should be within 20% of the labelled value. The device code, operating frequency, measured ERA and manufacturer's rated values are given in Table 1. For one of the six devices, the ERA was not within 20% of the rated value. For devices C and D the rated value of the manufacturer was not known.

<table>
<thead>
<tr>
<th>DEVICE CODE</th>
<th>FREQUENCY (MHz)</th>
<th>MEASURED ERA (CM²)</th>
<th>RATED ERA (CM²)</th>
<th>PERCENTAGE DEVIATION</th>
<th>BNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.1</td>
<td>3.9</td>
<td>4.4</td>
<td>13</td>
<td>6.16</td>
</tr>
<tr>
<td>B</td>
<td>3.3</td>
<td>3.3</td>
<td>3.9</td>
<td>18</td>
<td>6.16</td>
</tr>
<tr>
<td>C</td>
<td>1.1</td>
<td>3.25</td>
<td>unknown</td>
<td>—</td>
<td>7.72</td>
</tr>
<tr>
<td>D</td>
<td>1.1</td>
<td>3.25</td>
<td>unknown</td>
<td>—</td>
<td>7.84</td>
</tr>
<tr>
<td>E</td>
<td>1.1</td>
<td>3.05</td>
<td>5</td>
<td>64</td>
<td>8.96</td>
</tr>
<tr>
<td>F</td>
<td>0.87</td>
<td>3.5</td>
<td>4</td>
<td>14</td>
<td>8.08</td>
</tr>
</tbody>
</table>

Table 1. Results of measurements made on 6 ultrasonic beams

The quantity termed % deviation is defined as

% Deviation = \left( \frac{\text{ERA}_{\text{m}} - \text{ERA}_{\text{i}}}{\text{ERA}_{\text{m}}} \right) \times 100

where \text{ERA}_{\text{m}} is the value of the ERA as calculated from the measured raster scan and \text{ERA}_{\text{i}} is the ERA value indicated by the manufacturer.

Various international safety guidelines recommend an upper limit to radiated ultrasound energy to protect the patient against adverse biological effects. The World Health Organisation (WHO) limits the spatial average intensity to a maximum of 3 W/cm², while the International Electrotechnical Commission (IEC) states the same limit of 3 W/cm². However, in the continuous wave mode and the pulse wave mode. However, a safety aspect that is not considered in these limits, is the occurrence of high spatial peak intensities within the beam. High spatial peak intensities (also known as "hot spots") may cause damage to the patient's tissues and should therefore be avoided. As discussed earlier, these hot spots are usually quantified by the beam non-uniformity ratio (BNR). Although most safety standards do not specify a limit on the BNR, the TNO Medical Technology Unit of the Netherlands used a BNR ratio of 8 as a limit in a survey done on ultrasound therapy devices. This value is used as a guideline in the current study.

The BNR values for the six ultrasound beams under study are listed in Table 1. Of these, one had a BNR ratio above 8.

Summarizing the measurement of the ERA and BNR, it may be concluded that only two of the units comply with the requirements set for safety and accuracy, that is, a measured ERA deviating less than 20% from the labelled ERA, and a moderate BNR. No conclusion could be made on two further units due to a lack of manufacturer's data, while two units did not comply with the requirements set. This result is in accordance with results from similar investigations abroad.

Quality control and acceptance testing of equipment, dosimetry and fundamental studies of ultrasonic techniques all require the measurement of acoustic output. Hence, the measurement and specification of the acoustic output of medical ultrasonic equipment is an area of growing interest and concern.

REFERENCES


FORUM DEADLINES

In 1992 Physio Forum will continue to be published 8 times a year, in January, March, April, June, July, September, October and December. However, due to pressure of work, and to allow a margin for last-minute submissions, the schedule for deadlines has been slightly altered.

Please note that the deadline is 12:30 on the days listed below, and late submissions should be cleared by telephone. We cannot guarantee the publication of any late contribution.

<table>
<thead>
<tr>
<th>ISSUE</th>
<th>DEADLINE</th>
</tr>
</thead>
<tbody>
<tr>
<td>March</td>
<td>5 February</td>
</tr>
<tr>
<td>April</td>
<td>4 March</td>
</tr>
<tr>
<td>June</td>
<td>29 April</td>
</tr>
<tr>
<td>July</td>
<td>3 June</td>
</tr>
<tr>
<td>September</td>
<td>5 August</td>
</tr>
<tr>
<td>October</td>
<td>2 September</td>
</tr>
<tr>
<td>December</td>
<td>4 November</td>
</tr>
<tr>
<td>January</td>
<td>2 December</td>
</tr>
</tbody>
</table>

It would be advisable to keep a copy of these dates in the back of your diary for future reference.