Ultrasonics 58 (2015) 6–10

Contents lists available at ScienceDirect

Ultrasonics

journal homepage: www.elsevier.com/locate/ultras

Short Communication

Quantitative testing of physiotherapy ultrasound beam patterns within a clinical environment using a thermochromic tile

Gordana Žauhar [a], Đeni Smilović Radojčić [b], Denis Dobravac [c], Slaven Jurković [b,*]

[a] University of Rijeka, Medical Faculty, Department of Physics, Braće Branchetta 20, 51 000 Rijeka, Croatia
[b] Clinical Hospital Rijeka, Medical Physics Department, Krešimirova 42, 51 000 Rijeka, Croatia
[c] Clinical Hospital Rijeka, Department for Physical and Rehabilitation Medicine, Tome Strižića 3, 51000 Rijeka, Croatia

ARTICLE INFO

Article history:
Received 26 July 2014
Received in revised form 25 November 2014
Accepted 7 January 2015
Available online 17 January 2015

Keywords:
Ultrasound therapy
Thermochromic material
Quality assurance
Effective radiating area

ABSTRACT

The implementation of the non-standardized method developed at the National Physical Laboratory (UK) supporting the quality assurance of therapeutic ultrasonic beam parameters within a clinical environment is presented. The method consists of exposing an acoustic absorber tile, part of which contains a thermochromic pigment, to the ultrasonic beam, thereby forming an image of the two-dimensional intensity profile of the transducer. Nine different physiotherapy ultrasound treatment heads currently used clinically were tested using this method. Thermochromic images were postprocessed in order to estimate the Effective Radiating Area (ERA) for treatment heads operating within the frequency range from 1 MHz to 3.2 MHz, and nominal applied intensities in the range of 1–3 W/cm^2. Experimental results and comparisons with manufacturer specified values of ERA are presented. Differences in the experimentally derived results and the manufacturer values are typically well within 25%. The root-mean squared difference calculated over the nine treatment heads is 15.1%, with the thermochromic material tended to underestimate the ERA.

1. Introduction

Ultrasound has been used as a therapeutic technique of physical medicine for treating soft tissue injuries for over fifty years [1]. Propagation of ultrasound within tissue produces thermal and nonthermal (mechanical) effects. Those effects are used in physiotherapy [2] in order to raise tissue temperature and modify cellular activity to achieve clinical outcomes such as stimulation of bone repair [3] and decreasing pain. As ultrasonic energy is transmitted through tissue, it is attenuated due to absorption and scattering. Absorption leads to a conversion of acoustic energy to heat locally which is the primary consequence of attenuation in tissue. The clinical effects of the ultrasound depend on applied acoustic dose which can be defined as the energy deposited by absorption of acoustic wave per unit mass of the medium [4]. If the acoustic dose is too low there will be no significant clinical effects and if it is too large it can cause tissue injury [5]. Therefore, it is very important to measure and calibrate ultrasonic devices used in therapy, in order to prevent patient damage. A key safety related parameter is the effective acoustic intensity of physiotherapy system, obtained from the ratio of the maximum ultrasonic output power and the Effective Radiating Area (ERA), which should not be greater than 3 W/cm^2 [6]. The ultrasonic beam distribution generated by the treatment head is another important parameter concerning safety. Beam homogeneity can be quantified by the parameter called Beam Non-uniformity Ratio (BNR), which represents the ratio of the highest intensity in the field to the intensity averaged over the effective radiating area. Sometimes, that distribution can be highly non-uniform and can potentially generate regions of high local pressure, also called "hot spots" [7]. These regions may produce excessive heating in small regions of the tissue. Transducers with BNR > 8 are considered unsafe.

For quality assurance purposes, ultrasound physiotherapy treatment heads require periodic checks as their performance tends to deteriorate slowly, mainly resulting from minor damage to the transducer probe. Treatment heads can be checked using the standardized method which is based on the measurement of emitted ultrasonic power in addition to the scanning of the acoustic field carried out in water tanks using miniature hydrophones. These procedures require a specially equipped laboratory and are inconvenient for use in clinical environment. Thus an alternative method based on the use of thermochromic materials was proposed by Butterworth et al. [8]. The method is suitable as a rapid and simple

* Corresponding author.
E-mail addresses: gordana.zauhar@medri.uniri.hr (G. Žauhar), jenny_smilrad@net.hr (Đ.S. Radojčić), dobravac@gmail.com (D. Dobravac), slaven.jurkovic@medri.uniri.hr (S. Jurković).

http://dx.doi.org/10.1016/j.ultras.2015.01.006
0041-624X/

characterization tool. The method consists of coupling the emitting transducer to a specially designed acoustic absorbing tile parts of which contain a thermochromic pigment. These thermochromic pigments become colourless at locations where temperature is elevated above a certain threshold level (called "switch" temperature). The thermochromic tile used in the original publication contained thermochromic pigments with switching temperature around 30 °C. Energy deposition within the tile results in a temperature distribution within the tile which is closely related to the applied acoustic intensity distribution. Measurements for all treatment heads were performed using a constant distance from treatment head to the tile and equal exposure times while applied intensities were adjustable. The method provides information about whole thermal pattern and this close relationship with the intensity distribution provides the opportunity of a quantitative assessment of beam parameters.

This study investigated whether the new method could be employed within a clinical environment for the verification of ERA of physiotherapy ultrasound treatment heads. For this purpose, a thermochromic tile was used to check the characteristics of ultrasound treatment heads employed within the Clinical Hospital Rijeka. A systematic image capture protocol, explained in more details in the next section, has been applied. All thermochromic images were postprocessed in order to estimate treatment head ERA. The analysing tools were developed using Origin interface (OriginLab, OriginPro 8.5.0SR1). Experimental results and comparisons with manufacturer specified values of ERA are presented.

2. Materials and methods

Nine physiotherapy ultrasound treatment heads (able to function at frequencies close to either 1 MHz or 3 MHz) clinically used in Clinical Hospital Rijeka were tested by using thermochromic tile. The measurements for each ultrasound treatment head were repeated three times for respective measuring conditions.

The thermochromic tile used in measurements was obtained from National Physical Laboratory, UK and was manufactured by Acoustic Polymers Ltd. (Mitcheldean, Gloucestershire, UK). It consists of three discrete layers sandwiched together. These layers are based on a polyurethane material, previously developed and applied as a material for an absorbing target of a radiation force balance [9]. A detailed description of the thermochromic tile used in our measurements can be found in Butterworth et al. [8], where it is described as a Type B tile. The top layer, with thickness of 3 mm, is optically transparent with relatively low ultrasonic absorption and water matched acoustic impedance. The thermochromatic pigment whose switching temperature is around 30 °C is added to intermediate layer. The backing layer is white and strongly absorbing to ultrasound and gradually becomes visible through the thermochromic-loaded intermediate layer as it changes colour from blue to colourless. The typical experimental set-up is presented in Fig. 1. The thermochromic tile was removed from the refrigerator and maintained at room temperature for at least 1 h before the measurement to allow temperature equilibration.

The image capture protocol defined in [8] has been applied. Namely, a "reference" image of the tile next to a graduated ruler was acquired immediately prior to ultrasonic exposure. The ultrasound treatment head was placed on the tile with coupling gel as used in clinical conditions. Also, a securing weight was placed on the top of the treatment head in order to assure constant pressure on the tile. After ultrasonic exposure, the treatment head was removed and the tile wiped to clean of coupling gel. Approximately 10–20 s after insonation of the tile, optical images were acquired using a digital camera Optio WG-1 (Pentax Ricoh imaging Co., Ltd., Indonesia). The time interval was determined by the minimum time necessary for removing the weight, treatment head and wiping the tile free of coupling gel. Previous experimental observations [8] had shown that the visual image of the intensity distribution derived from the thermochromic tile remains constant for the first 40–60 s and consequently this time interval was chosen as optimal. All images were imported and postprocessed in order to estimate ERA. The estimation was made using our algorithm developed for postprocessing optical images. Once the reference and beam profile images were imported into the program, they are converted from colour to grey scale. Afterwards, a

Fig. 1. Experimental set-up showing the thermochromic tile, transducer, weight, ruler and digital camera on stand.

Table 1
The ERA values for physiotherapy ultrasound transducers clinically used in Clinical Hospital Rijeka.

Transducer	Frequency (MHz)	Effective radiating area (cm^2)		
		Specification	Calculated mean ± SD	Difference %
Cosmogamma F120	1	5	3.8 ± 0.1	−24.0
Sonopuls 992 ENRAF NONIUS	1	5	3.9 ± 0.3	−22.0
Sonopuls 992 ENRAF NONIUS	3	5	4.1 ± 0.1	−18.0
Gymna COMBI 200	1.1	4	3.7 ± 0.1	−7.5
Gymna COMBI 200	3.2	4.7	4.0 ± 0.1	−14.9
Gymna PULSON 100	1	4	3.5 ± 0.5	−12.5
Cosmogamma US-10	1	3.6	3.7 ± 0.1	2.8
MIXING 2	1	3.6	3.1 ± 0.1	−13.9
Cosmogamma F230	1	5	4.7 ± 0.1	−6.0