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# A REVIEW ON WATER BOLUS STRUCTURE INTEGRATION FOR NON-INVASIVE HYPERTHERMIA TREATMENT

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## ABSTRACT

*This paper presents a review of hyperthermia on a modified water bolus structure for breast cancer. Hyperthermia is an alternative treatment for cancer, which uses high heat to treat a cancer patient. Because of certain limitations, especially difficult to control focus position distance on the treated tissue has contributed to the low success rate of the treatment. In addition, excessive skin burn problems and adverse health effects on surrounding healthy tissue could occur as a result of high temperature applied on the skin and wide area of unwanted hot spots. Proper design on hyperthermia applicator can assist in reducing unwanted hot spots in the vicinity area while improving the focus position distance on the treated tissue, simultaneously. Meanwhile, massive skin burns can be overcome with the addition of water bolus. Based on previous research on water bolus, various designs have been investigated. However, further research needs to be carried out in order to provide more significant results on different stages of cancer. Therefore, in this research, a water bolus is investigated further by taking into consideration several factors to optimize the function of water bolus as a cooling system. Hence, it may reduce unwanted hot spots, minimize skin burn problem, while maintaining the required focus position distance on the treated tissue during the hyperthermia execution procedure. A deductive and inductive literature review approach is used to determine the research gap of current research on water bolus addition to hyperthermia procedure. A rectangular water bolus structure was used the most in hyperthermia research as it can be modified further, and it has the largest covered area for reducing unwanted hot spots on* *surrounding healthy tissue. The comparison analysis of different types of water bolus is presented.*

**Key words:** Non-Invasive, Hyperthermia, Water bolus, Cancer treatment, Skin burn.

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## 1. INTRODUCTION

Breast cancer is the most prevalent form of cancer affecting women globally and the leading cause of death among women in the world [1]. Researchers and scientists from all over the world have involved with the various method through simulation, experimental and clinical trials to improve the existing procedure to be more convenient and come out with the more effective cancer treatments [2],[3],[4]. Hyperthermia which also known as thermal therapy or thermotherapy, has attracted the interest of many researchers to be used as an alternative method to treat breast cancer patients [2],[5]. During hyperthermia treatment, the temperature is elevated between 40℃ - 45℃ where the range of the heat temperature can kill and destroy the cancer cells [2],[6]. Hyperthermia can be applied either invasive or non-invasively [5]. The invasive method is where the probe is inserted into the patient body, while non-invasive is where the applicators are applied externally or placed outside of the patient body. For non-invasive hyperthermia treatment, the applicator used is either Ultrasound (US) or Electromagnetic (EM) waves as a source of heating techniques [7]. Each of those heating techniques has its own advantages and disadvantages and selected based on the function or objectives of the treatment given.

Hyperthermia is safer than the traditional method and can enhance the efficacy of the conventional method [8]. However, previous research paper mostly discussed on the skin burn problem and not many papers discussed on unwanted hot spots obtained from undergoing the treatment [9],[10]. Hyperthermia treatment uses in various cancerous cells have been studied. Rectangle shape, deionized, or distilled water bolus is a preferred shape and liquid used for tissue cooling [4],[11]. Apart from that, the integration of water bolus to the applicators is also to create good impedance matching between the applicator and patient body [5].

In 2019, there are several publications on new material that have the same purposes of reducing skin burn problems. In the study of A.Ghasemlouy and S.Rajebi [2] a little, lightweight and wideband antenna has been designed. The purpose of the research is as the replacement of water bolus using the silicon layer, which can help decrease the percentage of burns to a minimum [2]. Another published research paper by Hana Dobsicek Trefina and Anna Storm [3] found a new way as alternative tools to by using hydrogels to improve heat delivery [3]. Most published hyperthermia cancer treatment use distilled or deionized water as water bolus, which is well known can help to solve skin burn problem.

Several limitations encountered by the previous researcher, such as the optimization of temperature to be used maximally within and at the restricted area in the target cancerous cells, is still a huge challenge in hyperthermia methods [12]. Different shapes of antennas were employed in hyperthermia for temperature increase purposes [13]. Finding the optimal temperature setting is considered difficult because available sources share the different settings, and some published papers provide limited information [14]. Previous clinical publications faced a challenge to control applicator powers, and water bolus temperature due to tissue homogeneities in every patient are time-varying and non-linear [15]. Therefore, this paper proposed a modified water bolus structure to reduce unwanted hot spots and skin burn problems during hyperthermia execution while maintaining penetration depth and focus position distance.

Figure 1 shows a method of research conducted in non-invasive hyperthermia treatment with water bolus (NHIWB) between 2015 to 2020. The simulation method is preferable, as the process can save more time in which the initial result can be collected before continuing with the experimentation or clinical works. Figure 2 shows the types of cancer implicated in previous research. Samples of cancer implicated either in the head, neck, brain, breast, muscles, and a few other places on the human body phantom.

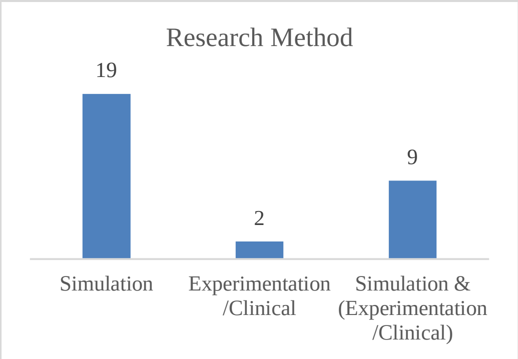


**Figure 1**. Conducted method

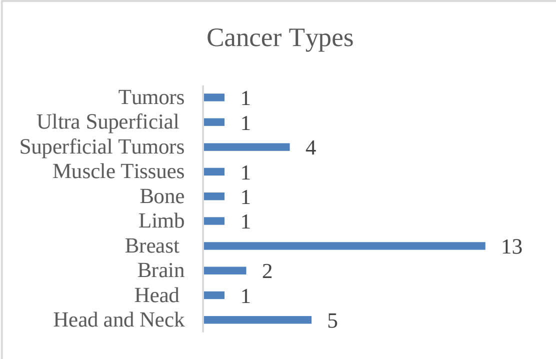


**Figure 2**. Types of cancers

Table 1 shows the list of antennas and research methods used and conducted by previous researcher, respectively. Microstrip shows the highest preferred antenna used in the research due to its many interesting characteristics such as lightweight, easy to manufacture, and suitable in hyperthermia treatments. Simulation represent the highest research method where the techniques are more flexible in conducting the research.

**Table 1** Research publication on NHIWB

| **Types of antenna used in NHIWB** | **Publication** | | | | | | **Total** | **Research Method** |
|---|---|---|---|---|---|---|---|---|
| | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | | **S: Simulation E: Experiment C: Clinical** |
| Microstrip | [11],[16], [17], [18] | [19], [4] | [5],[6],[20], [21],[22], [23] | [24],[25] | [2],[9], [26],[27] | [28],[29], [30] | 21 | S:12, E/C: 1 and S&E: 8 |
| Bow-Tie | | | | [31],[32] | [3] | | 3 | S: 2 and E/C: 1 |
| Waveguide | | | | [24] | | | 1 | S:1 |
| Dipole | [33] | [34] | [35] | | [36] | | 4 | S:4 |
| BSD2000-3D/MR system | [37] | | | | | | 1 | S & C: 1 |

## 2. WATER BOLUS FOR HYPERTHERMIA PROCEDURE

Figure 3 and Figure 4 shows water bolus liquid/material consumption and shape, respectively. From Figure. 3, as observed, the highest consumption is deionized water, followed by distilled water. Several researchers come out with new materials such as oil, hydrogel, and silicon, enriching the available material for use in hyperthermia. Figure. 4 shows the form of the water bolus, which is mostly in a rectangular shape. However, limited information can be extracted from the previous publication on the water bolus shape and material cover.

Most research aims to improve heating deposition on cancer target cells. Hana and Anna [3], for example, conduct research to improve heat delivery during the treatment. A research study by Sergio Curto et al. [18] aims to improve patient comfort, enhance energy deposition, and reduce power requirements. Publication paper from Aleix Garcia-Miquel et al. [4], on the other hand, aims to increase energy deposition and be able to concentrate on various parts of cancer cell location.

Apart from that, research by Kasumawati et al. [9] aims to enhance penetration depth, increase focusing capability, and reduce unwanted hot spots. Publication from A.Ghasemlouy and S.Rajebi [2] and Ki Joon Kim et al. [17] both intended to reduce skin burn overheating. The studies also aim to reduce the problem from water bolus using alternative material as a cooling item and improve heating depth, respectively.

Most research concerns and focuses on healing properties and less research discuss techniques to reduce skin burning and the problem of unwanted hot spots. Therefore, a complete study on non-invasive hyperthermia treatment integrates with water bolus information will be carried out to reduce the limitation.

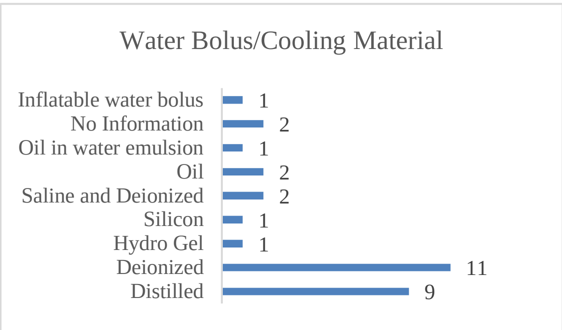


**Figure 3**. Coolant Material

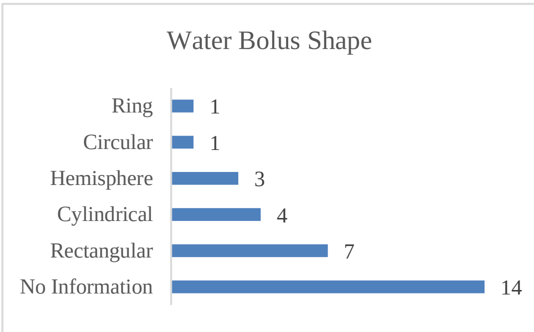


**Figure 4**. Water bolus shape

## 2.1. Design of Experiment

Figure 5 and Figure 6 show experiment 1 and experiment 2 architecture in conducting the research. The objectives of the design of experiment 1 are to investigate the most suitable antenna and operating frequency to be used in this research. Figure 4 shows the flowchart of microstrip applicator development. The research starts with breast analysis and continues with the design of breast phantom. The rectangular and circular shape of the antenna will be considered and design for evaluation purposes. The best frequency will be used in hyperthermia study and selected from three different frequency which are 434 MHz, 915MHz and 2.45GHz.

The objectives of the design of experiment 2 are to investigate the most suitable structure, liquid, and material cover for water bolus. Figure 6 shows the water bolus development process. The process starts with the selection of a water bolus structure, including thickness, width, and height. Next, for liquid selection, it will start with distilled water, deionized water, and followed by other suitable liquid. Apart from the selection of the best liquid, the selection of material for liquid cover will also be conducted. Simulation is performed using SEMCAD X to find the best SAR distribution. Once the best result is known, the final stage of hardware development is carried out to check and validate the results.

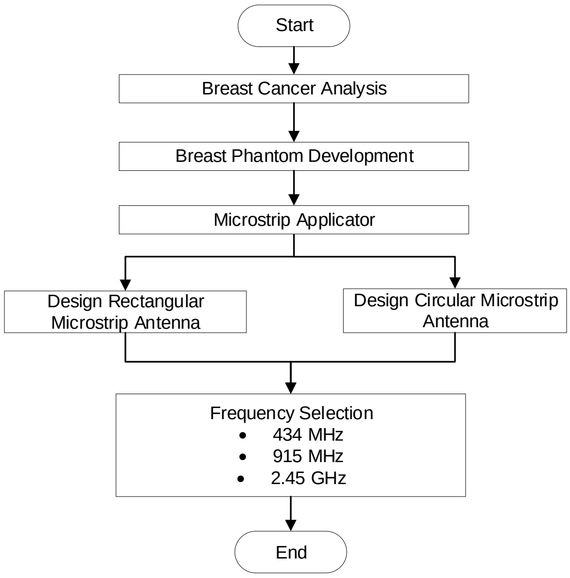


**Figure 5**. Microstrip Applicator Development.

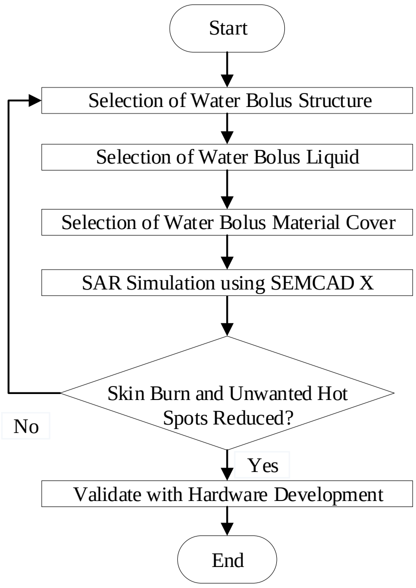


**Figure 6**. Water Bolus Development.

## 2.2. Thermal Equations used for SAR and Temperature Calculation

Specific absorption rate (SAR) is the rate of energy absorption per unit mass, inside the biological tissue when exposed to an electromagnetic field [33]. SAR formula [6] with $\sigma$

(S $m^{-1}$) the electric conductivity and $\rho$ (kg $m^{-3}$) the tissue density.

$$\mathrm{PD} = \frac{\sigma}{2}\left\|\vec{E}\right\|^{2} = \rho . SAR \tag{1}$$

Thermal simulations were performed by solving Pennes' bio heat equation [6]

$$c\rho \frac{\partial T}{\partial t} = \nabla.(k_{tis} \nabla T) - c_b W_b (T - T_{art}) + PD \tag{2}$$

where $c$ is the specific heat capacity $(\mathrm{J\,Kg^{-1}{}^{\circ}C^{-1}})$, $k_{tis}$ (W $m^{-1}$°C$^{-1}$) is the thermal conductivity, $c_b$ the specific heat capacity of blood, $W_b$ (kg $m^{-3} s^{-1}$) the volumetric perfusion rate and $T_{art}$ is body core temperature.

# 3. PROPOSE WATER BOLUS STRUCTURE

Figure 7 shows the proposed research design for this study. The microstrip antenna integrates with the rectangular or circular shape of the water bolus placed on the surface of the breast phantom. Non-invasive hyperthermia treatment will be conducted where the applicator (antenna and water bolus) is applied externally on the breast phantom. A small red circle indicates existing cancerous cells, which is the target to be destroyed using a non-invasive hyperthermia technique. The last layer represents patient tissue muscles.

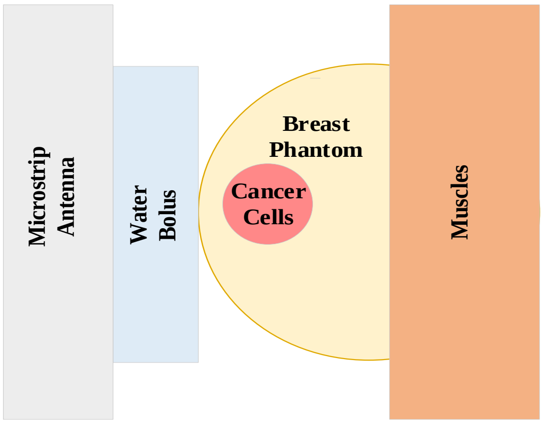


**Figure 7** Proposed Research Design

A newly modified water bolus structure with rectangular or circular shape design is proposed. The rectangular or circular shape water bolus is selected to cover as much treated area as possible and match with the rectangular or circular antenna. The shape of water bolus and antenna must be in the same shape, to ease any modification, be it antenna or water bolus structure. Distilled water, deionized water, and a few other liquids will be tested through the simulation process in order to get the best liquid or material as a coolant on the treated tissues. PVC, plastic bags, and a few other suitable materials will be investigated for selection as a water bolus cover. The investigation on the percentage of reduction on skin burn problems and unwanted hot spots will be carried out while retaining the good penetration depth and focus position distance.

## 4. CONCLUSION

An overview of non-invasive hyperthermia treatment integrate with water bolus was presented. Most of the papers that have been reviewed are emphasized on superficial categories and several on deep hyperthermia. Water bolus is essential to work as a coupling medium and cooling material in hyperthermia treatment. The usage of water bolus can help to reduce skin burn problems and unwanted hot spots. Furthermore, most publications have concerned about heating optimization, heating homogeneity, the effective therapeutic temperature inside cancer, and efficient power deposition. However, limited information and less work have been done to reduce massive skin burn problems and unwanted hot spots using suitable water bolus. Limited information observed from the previous study conducted on suitable water bolus shape and material covered for water bolus. In addition, not much publication discusses both skins burn problems and unwanted hot spots using hyperthermia techniques. In conjunction with that, several factors on water bolus will be investigated further to enhance the function of a water bolus. The newly modified water bolus structure is therefore proposed to reduce skin burning and unwanted hot spots while simultaneously improving the depth of penetration and the focus position distance.

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