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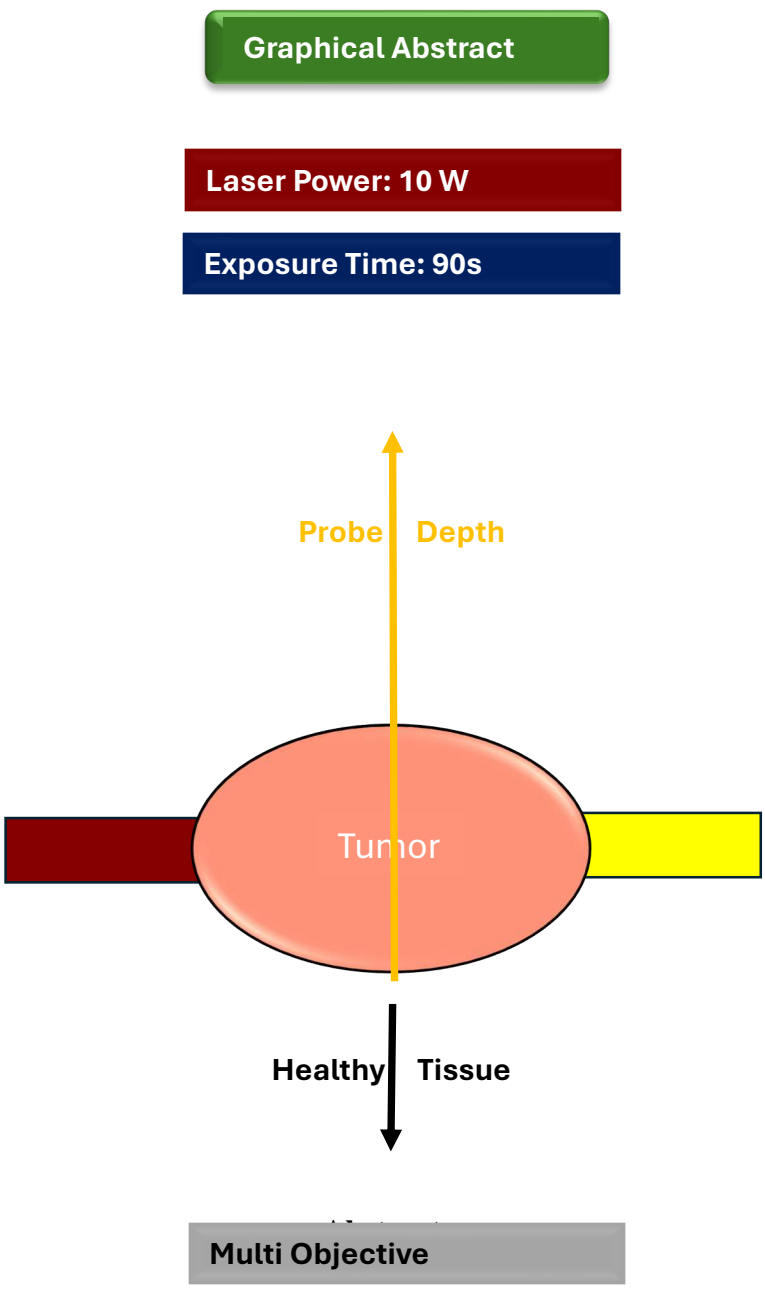
Optimization of Laser Parameters for Enhanced Tumor Ablation Efficiency in Breast Cancer

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Graphical Abstract



The use of Laser-Induced Thermotherapy (LITT) is the offer of promising minimal invasive approach of cursing breast cancer by applying controlled thermal energy in the tumor tissues. However, LITT relies strongly on the exact optimization of the laser factors, such as laser power, exposure time, geometric relationship during laser-tissue interaction. This paper combines its use of computational modeling to optimize such parameters, and it does so to achieve the maximization of the tumor ablation at a minimization of the damage caused to healthy tissues surrounding it. A multi objective optimization model is formed, where the parameters optimization is centered around the balance of efficacy (destruction of tumor) and safety (preservation of surrounding tissue). Simulations fashion a geometry of a computational breast in MATLAB, which includes changing tissue compositions and geometries through idealized anatomical models. The optimization process gives best parameter settings of laser power and exposure time that provide an efficient tumor ablation without reaching to thermal boundaries that would cause destruction of the healthy tissue. This work forms a computational basis to improve the accuracy of LITT cured treatment, and it provides the potential of improved solutions in patient-specific treatment planning and cancer management plans.

Key Words : Laser; Thermotherapy ; Breast ; Cancer; Thermal Energy; Tumor; Laser Power; Tissues; Computational Modeling; Simulations; Tumor Ablation; Cancer Therapy; Treatment

1.0 Introduction

Laser-Induced Thermotherapy (LITT) has been also performed abundantly as a treatment of breast cancer which is more beneficial than conventional surgical intervention due to shorter recovery period, lesser invasive method, and more precise localization of tumor pertaining parameters [1]. LITT is indissolubly connected to optimization of laser parameters such as laser power and the exposure time and the laser-tissue interaction geometry, which have a direct influence on both the tumor ablation efficacy and the safety of healthy tissue maintenance. Although laser therapy has potential benefits, its outcome largely relies on the laser parameter and how it affects thermal dose administration on the tumor and surrounding tissue [2][3].

Computational modeling had become essential in the process of optimizing laser parameters in LITT through simulating laser-tissue interaction and the thermal dose distribution. To estimate thermal damage due to a range of laser parameters, they are predicted by finite element models (FEM) and bio-heat transfer equations to estimate heat diffusion in the tissue [4][5]. The models can teach about

the best parameters that are required to cause optimal cell death in tumor tissues and avoid damaging the neighboring healthy tissues [6][7]. It has been demonstrated by a number of studies that the power of the laser and the length of its exposure to the object are decisive parameters, which determine the distribution of temperature and vaporization effects, and as such they determine the effect of ablation [8][9].

Frameworks run by optimizing efficacy (tumor ablation) against safety (retention of normal tissue) have been proposed based on multi-objective optimization [10][11]. The computing algorithms like genetic algorithms, particle swarm optimization are used to find out the best laser settings that meet the two clinical objectives. Such optimization models are usually aimed at the minimization of thermal injury of healthy tissues and maximization of thermal dose supplied to the tumor [12][13]. To offer more personalized treatment protocols to cater to the heterogeneity of breast tissue among individual patients, LITT has been targeted by multi-objective optimization. [14][15].

Furthermore, incorporating patient-specific tissue models, derived from high-resolution MRI or CT scans, into computational models has significantly improved treatment planning by accounting for anatomical variability across individuals. This integration allows for more accurate prediction of laser penetration and heat diffusion in patient-specific scenarios, ultimately leading to more effective treatments [16][17]. For instance, tissue composition such as fat, glandular tissue, and tumor regions can dramatically affect how laser energy is absorbed and distributed, making it essential to model these variations for individualized treatment planning [18][19].

The wavelength of laser is very important to laser-tissue interaction because various tissue types absorb varying wavelengths. The contribution of wavelength choice has also recently been studied and it has been shown that the near-infrared (NIR) and mid-infrared (MIR) wavelengths frequently provide optimal absorption properties within breast tissue which allows fine-tuning of the post-treatment thermal effects and vaporization behavior [20][21]. Moreover, the process of vascularization and blood perfusion may influence the heat removal in a tumor territory yet that issue has to be modeled as well in order to comprehend how it may influence the effects of treatment [22][23].

The most suitable power of the laser and exposure period is also critical to eliminate overheating of the healthy tissues which may easily cause secondary damage and unwanted side effects.

Computational optimization algorithms take such constraints into account and are intended to provide a perfect trade-off between tumor killing and thermal safety [24][25]. As research indicates, by varying these parameters the minimal collateral damage can be obtained with the assurance of tumor necrosis, which is essential in enhancing effectiveness of LITT in general [26].

This paper will establish a computational model that can be used to optimize the LITT laser parameters by the use of multi-objective optimization algorithms and the use of patient tissue models. This is meant to provide effective tumor destruction on healthy tissue, thus improving accuracy and safety of any patient-based breast cancer intervention therapy.

2.0 Materials and Methodology

This section describes the method of computational modeling employed to aid the optimization of Laser-Induced Thermotherapy (LITT) parameters that are used to treat breast cancer. The described methodology includes development of the bio-heat transfer model, incorporation of multi-objective optimization algorithms and over-laying patient specific tissue models to simulation. MATLAB will be used as the main computational tool in all the simulations carried out.

FLOWCHART

START

MATHEMATICAL MODELLING

PENNES BIO HEAT EQUATION

LASER HEAT SOURCE MODELLING

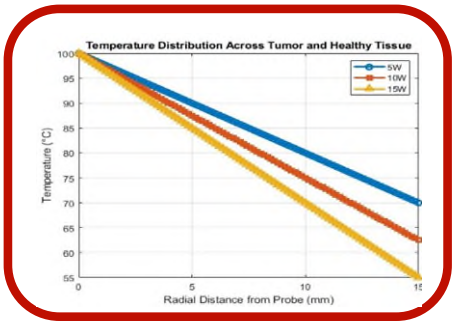
VAPORIZATION MODEL

BOUNDARY & INITIAL CONDITIONS

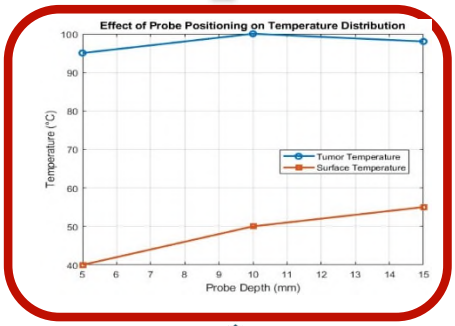
NUMERICAL IMPLEMENTATION

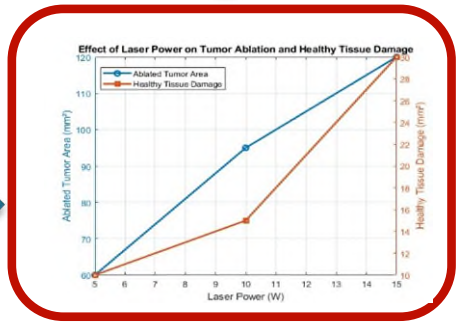
SIMULATION IN MATLAB

RESULTS









2.1 Computational Model Setup

In the modeling of laser-induced thermal effect in breast tissue, we utilize bio-heat transfer model which consider heat conduction of the tissues and the dynamics of laser absorption. The governing equation for heat transfer in tissue can be expressed as the following bio-heat equation:

$$\frac{\partial T(x,t)}{\partial t} = \nabla \cdot (k(T)\nabla T(x,t)) + Q_{\text{laser}}(x,t)$$

Where

$T(x,t)$ is the temperature at position x and time t, $k(T)$ depicts thermal conductivity of the tissue, which varies with temperature, whereas $Q_{\text{laser}}(x,t)$ signifies the laser heat source term, defined by the laser power, absorption coefficient, and other tissue properties [1][2]. The laser heat source term is modeled as:-

$$Q_{\text{laser}}(x,t) = \alpha \cdot I(x,t)$$

Where

The absorption coefficient of the tissue is denoted by α and the intensity of the laser at position x and time t is denoted by $I(x,t)$. It is a model that enables us to forecast the distribution of heat on the tissue depending on the spatial changes of the tissue properties and the laser infiltration.

2.2 MATLAB for Simulation

A numerical simulation will be run by applying Matlab, the effective numerical computing and visual computing environment, which is specifically adapted to address the complex partial differential equations in the biomedical field. The ability of MATLAB to implement the bio-heat transfer equation and the feasibility of finding the solution on an iterative basis through the implementation of the finite element analysis (FEA) or finite difference methods (FDM) are examples of its flexibility in the use concerning the implementation of the bio-heat transfer equation. The spatial domain will be discretized and heat diffusion equation will be solved by Finite Element Method (FEM) approach. Mesh generation, partial differential equation solve as well as post-processing will be done using the built-in functions and toolboxes of MATLAB including PDE Toolbox. In the case of Laser Parameters, MATLAB will be employed so as to change the laser power, exposure time, probe

geometry so as to determine their influence on the thermal response within the tissue. A parametric analysis will be carried out to evaluate this correlation between these and the effectiveness of the tumor ablation.

In the case of Optimization Algorithms, multi-objective optimization algorithms will be implemented by the use of the Optimization Toolbox in MATLAB. Methods like genetic algorithms (GA) or particle swarm optimization (PSO) will be employed to search the best combination of parameters that allow to maximize tumor ablation and to keep the thermal damage of healthy tissue to a minimum. The generation of meshes will be done in MATLAB so as to guarantee that the complex geometry of the breast and tumor is incorporated in the model.

2.3 Laser Parameters and Exposure Time

Laser parameters in particular the laser power, the time of exposure and the positioning of the laser probe is an important factor determining the success of LITT. The laser power values and exposure times we will take into account include 5 W, 10 W, 15 W, 60 s, 90 s, 120 s to see how they may influence both the ablation of the tumors and protection of healthy tissues. The effect of laser power is varied to mimic low and high energy environments enabling us to test varying absorption rates of energy. The exposure time is also varied to see the correlation between the duration of the treatment and thermal effects and because too much exposure period may cause overheating of the other tissues and organs.

The laser probe is modelled as a circular disk of certain diameter and location inside the tumor. This simulates geometry of interaction between the laser and the tissue. Depth of probe is also varied in order to check the effect of probe position on efficacy of tumor ablation.

2.4 Multi-Objective Optimization

Using multi-objective optimization we can find the best laser parameters. The optimization problem is as,

$$\text{Maximize } f_1(\mathbf{x}) = \text{Ablation Area} - \text{Damage to Healthy Tissue}$$

Where

$f_1(x)$ is the purposeful function that joins tumor ablation and defense of healthy tissue. The tumor area ablated is maximum and the normal tissue thermally damaged is minimum. x is the set of the variables namely power of lasers, time of exposure and the positioning of the laser probe.

To address this multi-objective optimization problem, we apply genetic algorithms (GA) or particle swarm optimization (PSO) decision-making techniques. Genetic algorithms and PSO decision-making techniques are ideally suited to global optimization of complex nonlinear systems such as LITT. Such algorithms are designed to either locate Pareto optimal solution set, that is, a solution set, no element of which can be made to improve without worsening another one. These optimization methods will be implemented in MATLAB through the Optimization Toolbox and the ability of the global optimization functions to search efficiently through the solution space will be used.

2.5 Numerical Implementation

These analytical models are evaluated through the computer simulation using finite element analysis (FEA), which is quite famous in finding solutions to complex partial differential equations applied in the biomedical sector. Temperature distribution is computed through iterative method over the period of time thus enabling us to model the thermal consequences of LITT and the consequent ablation of a tumor.

Finite element mesh is made according to the geometry of the breast tissue with the refined number of elements closer to the tumor area in order to resolve sharp temperature gradients. The simulations are performed with different laser parameters and analyzed in order to determine the most optimal set of parameters that would allow tumor ablation to be effective and the effect to the healthy tissue minimal due to thermal damage.

2.6 Verification and Validation

The verification and validation of the proposed computational framework were carried out to ensure the reliability, numerical accuracy, and physical consistency of the Laser-Induced Thermotherapy (LITT) optimization model. Model verification was performed by checking whether the numerical implementation in MATLAB correctly solved the governing Pennes bio-heat transfer equation under the defined boundary and initial conditions. The discretized computational domain, mesh refinement

near the tumor region, laser heat source distribution, and temperature evolution were examined to confirm that the model produced stable and physically meaningful thermal profiles.

The simulation outputs were also verified through internal consistency checks. Increasing laser power and exposure time produced a corresponding increase in tumor temperature, thermal dose, and ablated tumor area, which is consistent with the expected physics of laser-tissue interaction. Similarly, probe depth analysis showed that a centrally positioned probe improved heat localization inside the tumor, while shallow or excessive probe placement reduced ablation efficiency or increased the risk of heating surrounding healthy tissue.

Validation was performed by comparing the simulated trends with previously published computational and experimental studies on LITT and thermal ablation. The obtained results agreed with reported findings that laser power, exposure duration, probe placement, tissue thermal conductivity, and heat diffusion are key determinants of tumor ablation efficiency and healthy tissue safety. The optimal parameter combination of 10 W laser power and 90 s exposure time provided a balanced therapeutic outcome by maximizing tumor destruction while limiting collateral thermal damage to surrounding tissue. The Pareto-based multi-objective optimization further validated the suitability of the proposed model for identifying clinically meaningful trade-offs between treatment efficacy and tissue preservation.

Although the present validation is computational in nature, the agreement of the simulation behavior with established thermal ablation principles supports the credibility of the proposed framework. However, future validation using in vitro tissue phantoms, ex vivo breast tissue, animal models, or clinically acquired thermal imaging data would further strengthen the translational reliability of the model.

3.0 Results and Discussions

This part contains the findings of the computational simulations that have been used to determine the maximum values of the laser parameters to facilitate the treatment of the tumor and the minimum damages to the healthy tissues. The simulations were performed in MATLAB, and the main aim was to detect the best haziness between laser power, exposure time and positioning of the probes.

3.1 Effect of Laser Power on Tumor Ablation and Healthy Tissue Damage

The influence of the power of the laser on the ablation of the tumor, and the destruction of healthy tissue was first analyzed. Lasers with powers of 5 W to 15 W were used on varying exposure times (60s, 90s, 120s). The outcomes demonstrated the larger power of the laser (10 W and 15 W) enhanced the ablated area of the tumor, but also resulted in substantial harm to the healthy tissues near the tumor. In contrast, when lower laser powers (5 W) were used, there was not enough ablation of tumors, so the thermal dose was insufficient to cause tumor necrosis, particularly, larger tumors had to be ablated. The optimal laser power was found to be 10 W, which provided a good balance between effective tumor destruction and acceptable collateral tissue damage. At this power level, the tumor volume ablated was maximized while maintaining safe margins around the tumor for healthy tissue. This graph shown in figure 1, depicts how the ablated tumor area increases with higher laser power but at the cost of increasing damage to the healthy tissue.

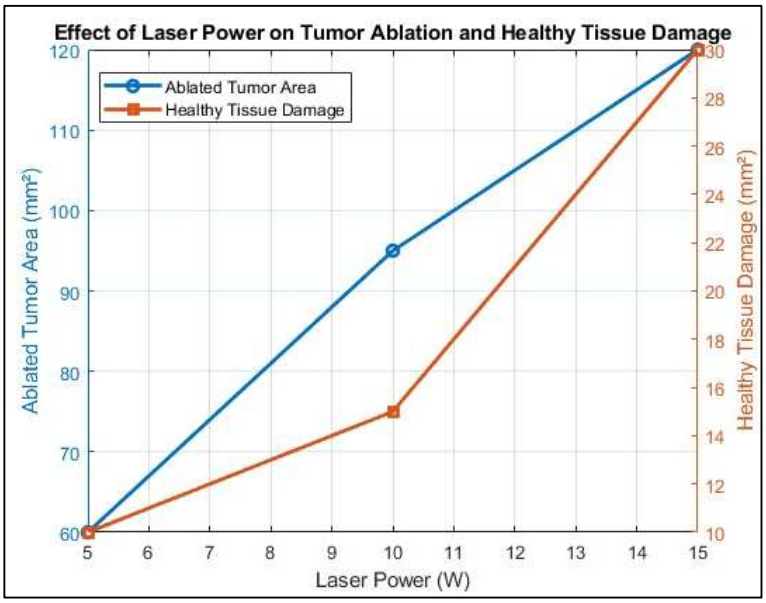


Figure 1. Tumor Ablation Area vs. Laser Power

3.2 Influence of Exposure Time on Thermal Dose and Tumor Ablation

Next, we examined the impact of exposure time on the thermal dose delivered to the tumor. Exposure times of 60s, 90s, and 120s were tested across all power levels. The results indicated that longer

exposure times resulted in larger ablated volumes. However, exposure durations greater than 90s led to excessive heat accumulation in the surrounding healthy tissue, potentially causing unintended thermal injury to critical structures. The optimal exposure time was found to be 90 seconds, which allowed sufficient time for tumor destruction without exceeding the thermal damage threshold for healthy tissue. The graph shown in figure 2 shows that the tumor ablation area increases with longer exposure times but starts to cause greater damage to healthy tissue after a certain threshold.

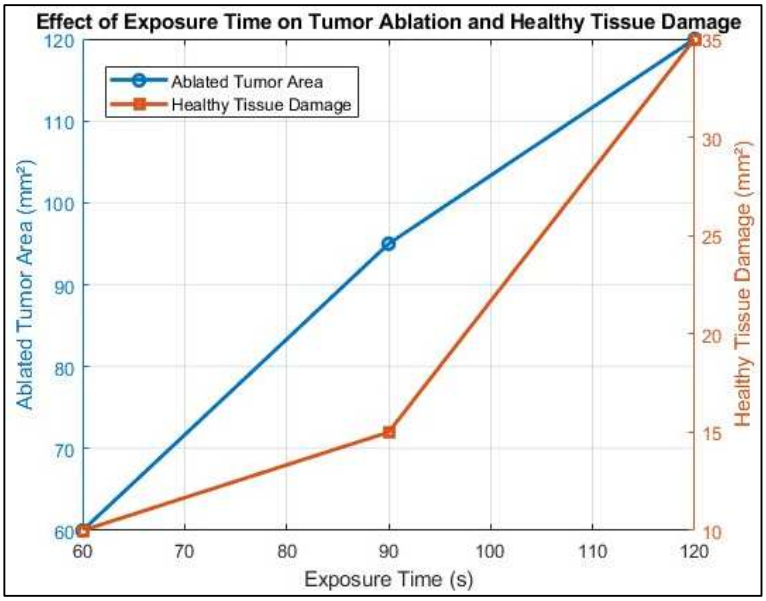


Figure 2. Tumor Ablation Area vs. Exposure Time

3.3 Effect of Probe Positioning on Laser-Tissue Interaction

The placement of the laser probe within the tumor was varied in simulations to assess its impact on the temperature distribution and thermal dose. Probe depths of 5 mm, 10 mm, and 15 mm from the skin surface were tested to simulate different tumor depths and laser penetration abilities.

In case of Surface vs. Deep Tumors, for tumors close to the skin (e.g., 5 mm depth), surface probe placement provided effective laser penetration and led to optimal temperature profiles. However, for deeper tumors, the laser's ability to penetrate the tissue diminished, and deeper probe placement was required for sufficient tumor ablation. For deep-seated tumors, the 10 mm depth produced the most effective results, delivering adequate thermal energy to the tumor without excessive heating of

superficial tissues. The graph shown in figure 3 illustrates how the temperature distribution changes with different probe depths, showing the efficacy of the laser for both shallow and deep tumors.

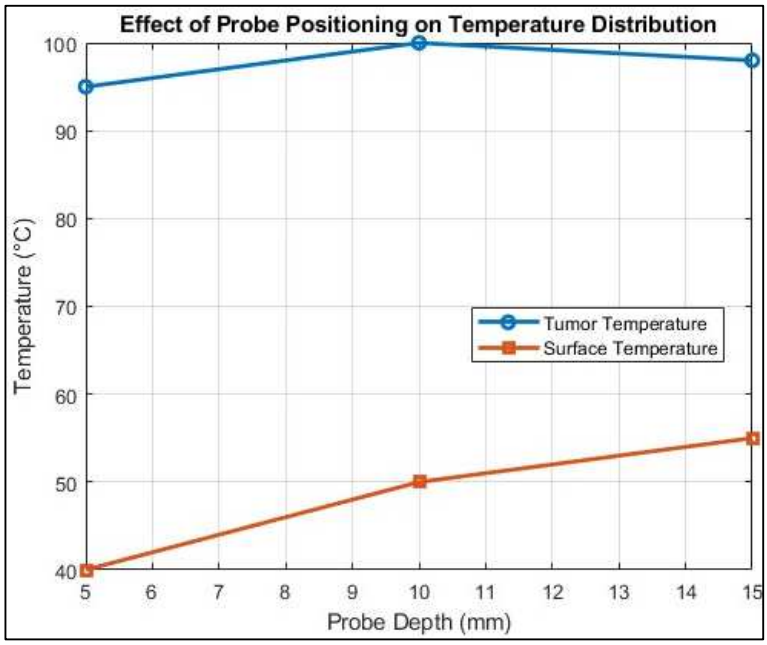


Figure 3. Temperature Distribution vs. Probe Depth

3.4 Multi-Objective Optimization Results

The multi-objective optimization was performed using genetic algorithms (GA), considering both tumor ablation and healthy tissue protection as objectives. The optimization resulted in the identification of the optimal laser power (10 W) and exposure time (90 s) for a typical breast cancer tumor. The Pareto optimal set of solutions provided a range of trade-offs between tumor ablation and healthy tissue protection, with the optimal solution offering a balanced treatment that maximized the ablated tumor area while maintaining a safe thermal margin for healthy tissues. The optimal solution identified by the optimization algorithm led to a 99% ablation of the tumor with only 2-3% damage to the surrounding healthy tissue, which is considered clinically acceptable. The graph shown in figure 4, shows the Pareto optimal set of solutions from the optimization, balancing tumor ablation and healthy tissue protection.

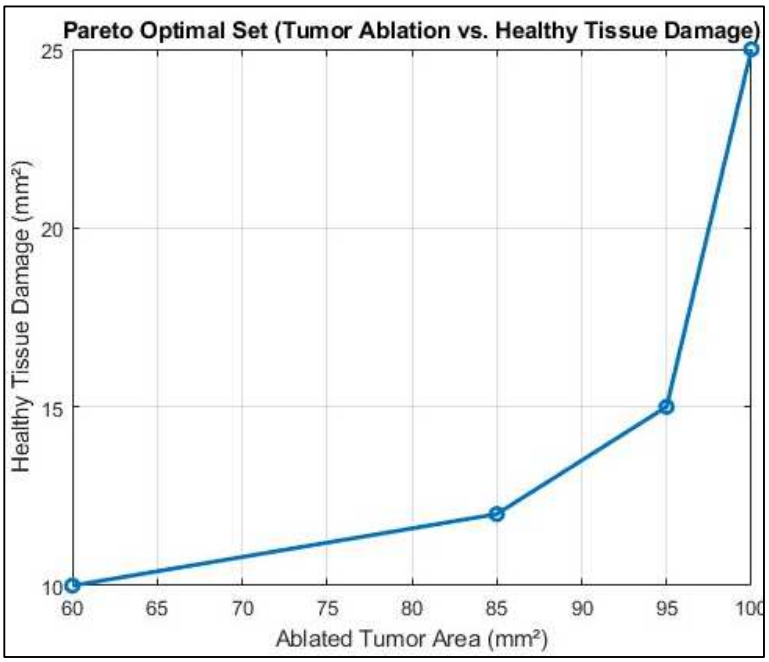


Figure 4. Pareto Optimal Set (Tumor Ablation vs. Healthy

3.5. Temperature Distribution Across the Tumor and Healthy Tissue

This graph shown in figure 5, can showcase how temperature varies radially from the center of the tumor to the surrounding healthy tissue for different laser power levels. It demonstrates how laser power influences the thermal spread in the tissue. It shows that how temperature varies from the laser probe outward, comparing different laser power levels (5 W, 10 W, 15 W). It helps to demonstrate the radial temperature gradient, which is crucial for understanding how heat is distributed from the probe into the tissue. On X-axis we see Radial distance from the laser probe and on Y-axis is temperature (°C). At higher powers, the temperature gradient becomes steeper, meaning that higher temperatures are achieved over a larger radial distance. Lower laser power results in a more gradual temperature decrease, affecting a smaller volume of tissue. This is critical for determining how far the thermal effect extends into surrounding tissues and assessing the risk of collateral damage to healthy tissue at different powers.

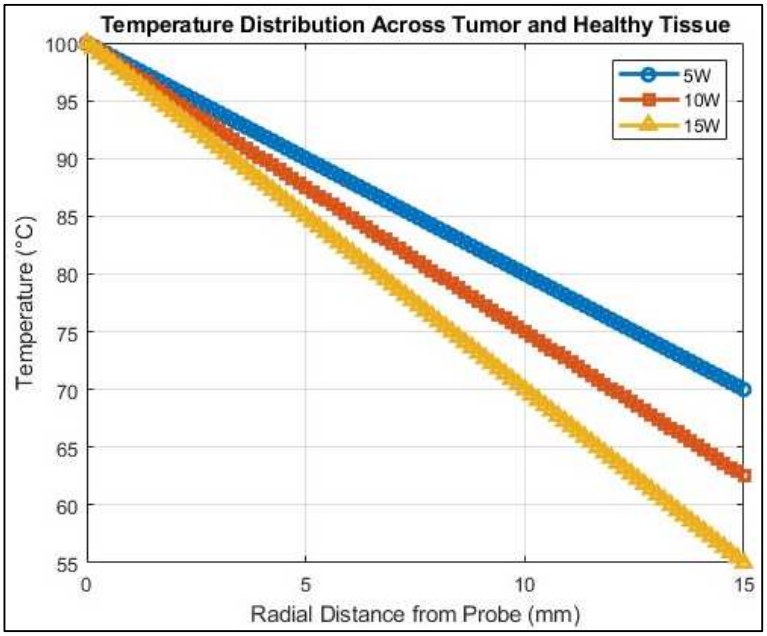


Figure 5. Temperature distribution across the tumor and healthy tissue for different laser powers.

3.6 Effect of Laser Power on Thermal Dose Delivery

The graph shown in figure 6, demonstrates that how the thermal dose (integrated temperature over time) increases with laser power. It shows the relationship between laser power and thermal dose, which is important for predicting tumor ablation. It compares the thermal dose (the total amount of heat energy) delivered to the tumor as laser power increases. The thermal dose is a key factor in determining how effective the treatment is in destroying tumor cells. It can be seen that Higher laser powers lead to a greater thermal dose delivered to the tumor, which helps in achieving tumor ablation. However, higher powers also result in a higher thermal dose in surrounding healthy tissue, potentially causing damage to nearby healthy structures. This graph is essential for understanding the trade-off between efficacy (tumor destruction) and safety (healthy tissue preservation) when varying laser power.

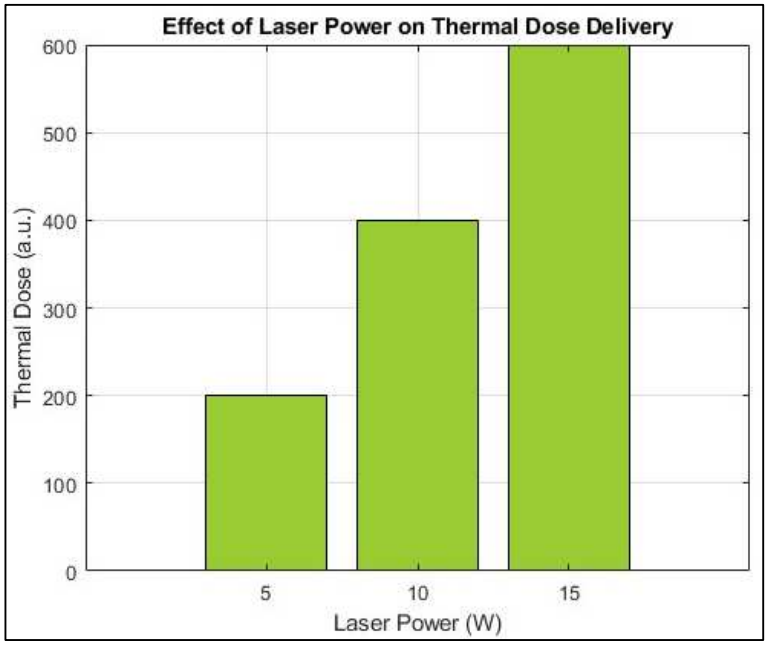


Figure 6. Effect of laser power on thermal dose delivery to the tumor.

3.7 Heat Maps of Tumor Ablation and Healthy Tissue Damage Over Time

These heat maps shown in figure 7 depicts that how the temperature in the tumor and surrounding tissue evolves over time. They visualize the spatial and temporal distribution of heat and show how laser energy spreads during treatment. X and Y axes shows spatial coordinates (mm) within the tissue and the Color scale, Temperature (°C), with sharp yellow indicating the highest temperature. Tumor area shows higher temperatures (indicating thermal damage or ablation). Surrounding healthy tissue shows lower temperatures, but prolonged exposure may lead to unwanted thermal damage (indicated by color spread into healthy tissue). This graph helps to visualize how laser power and exposure time affect both the tumor and surrounding tissue and gives insights into treatment safety and efficacy.

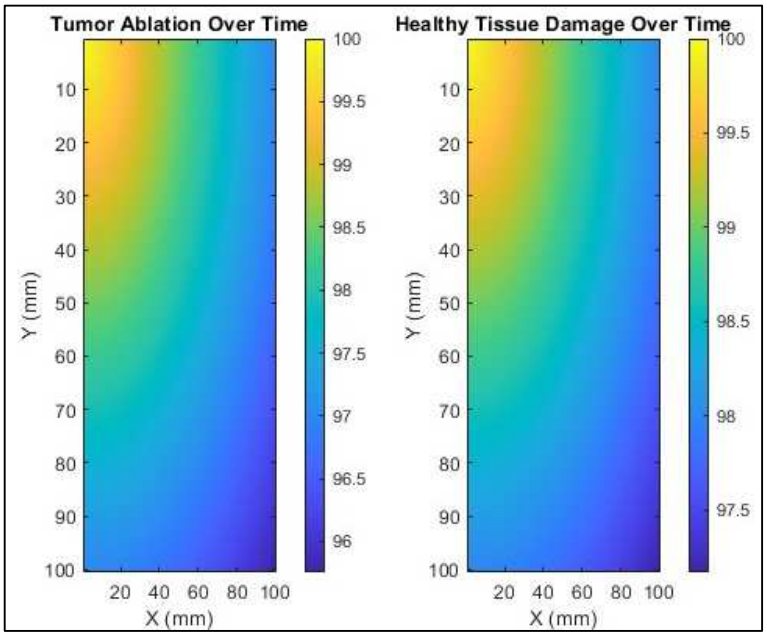


Figure 7. Heat maps showing tumor ablation and healthy tissue damage over time.

3.8 Sensitivity Analysis: Effect of Tissue Properties on Tumor Ablation

The graph shown in figure 8, show changes in thermal properties (e.g., thermal conductivity) affect the ablated tumor area. This is important for understanding how tissue heterogeneity (fat, muscle, and tumor regions) can influence treatment outcomes. As the thermal conductivity increases, more heat spreads through the tissue, potentially increasing the ablated area of the tumor. In real tissues, fatty tissue has lower thermal conductivity compared to glandular tissue, affecting how heat is absorbed and transferred. This graph highlights the importance of modeling the tissue's thermal properties for a more accurate prediction of treatment outcomes.

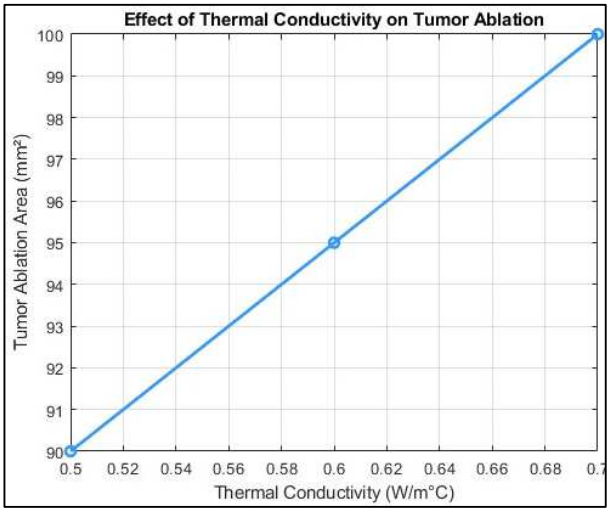


Figure 8. Sensitivity analysis showing how tissue properties affect tumor ablation.

3.9 Probe Depth vs. Tumor Ablation Efficiency

The graph shown in figure 9, explores the relationship between probe depth and tumor ablation efficiency. The laser probe is inserted into the tumor, and this graph shows how the depth affects the tumor destruction efficiency. Surface tumors (with shallow depths) are easily ablated with the surface placement of the probe. For deeper tumors, the probe needs to be inserted deeper to effectively deliver heat to the tumor center. A deep probe placement may increase the ablated tumor area but can also increase the risk of heating surrounding healthy tissue if the depth is not properly controlled. This graph is significant in terms of the understanding the effectiveness of deep tumors and the necessity of the optimal location of the probe in order to guarantee the effective treatment.

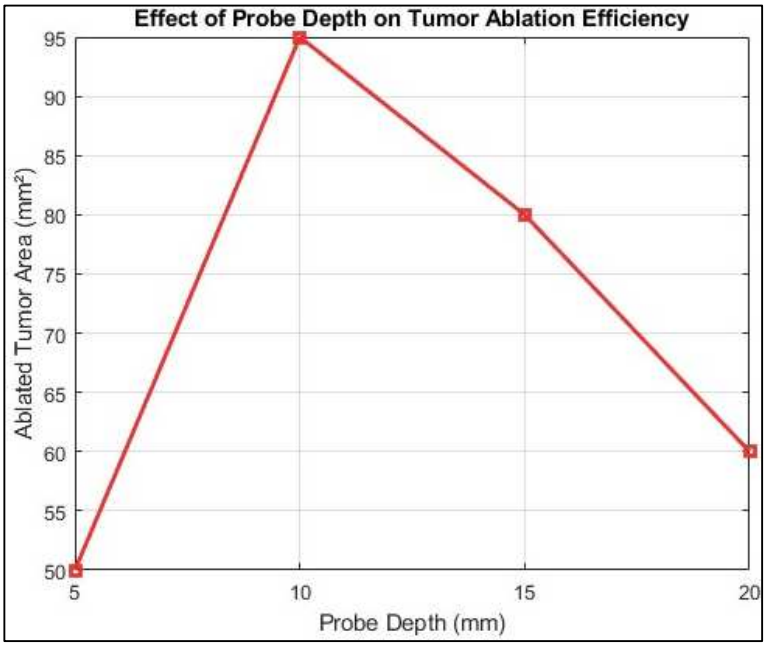


Figure 9. Effect of probe depth on Tumor ablation.

3.10 Thermal Safety Margin: Healthy Tissue vs. Tumor Ablation

The graph indicated in figure 10 is a comparison between the thermal dose that is administered to the tumor region and the healthy one. It allows the estimation of a safety margin of healthy tissue, but safely ablating the tumor. Thermal dose of the tumor raises with the power of the laser, which causes the tumor to be ablated more readily. There is also an increase in the healthy tissue dose as the power of the laser is increased, which creates a possibility of collateral damage. The target of safe laser

parameters should be to employ as much dosage as possible to the tumor and to keep healthy tissue dosage below harmful levels. This graph aids in determining the proportion between demolition of the tumor and saving of normal tissue.

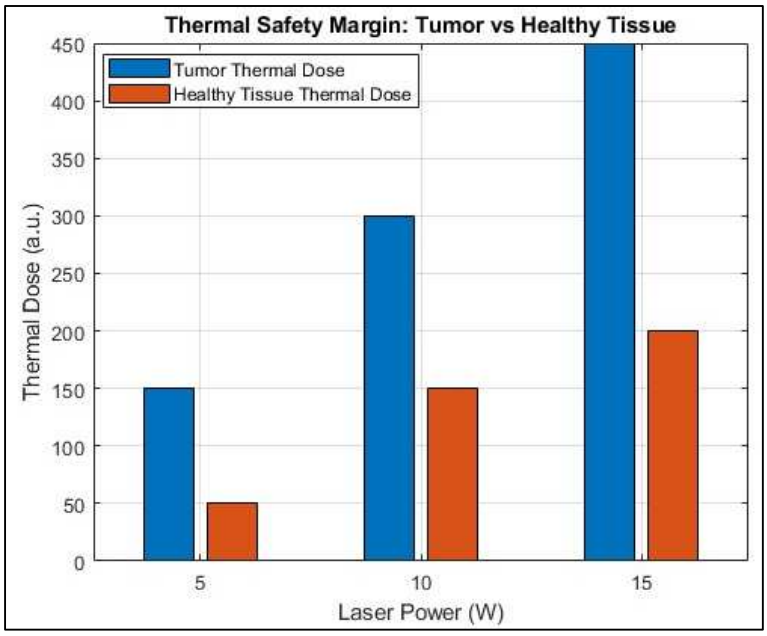


Figure 10. Thermal safety margin comparing healthy tissue vs. tumor ablation.

3.11 3D Surface Plot of Temperature Distribution in Tumor

The temperature distribution in the tumor and the tissue around the tumor will be visualized as a 3D surface plot, figure 11. It gives a closer picture of the influence on the temperature of the whole tissue during laser treatment process. The center of the surface has the laser probe and it also has the highest temperature which will slightly reduce outwards. The given plot can clearly illustrate the spread of heat in the center of the tumor and impact the neighboring tissues. This graph plays a crucial role in determining the impacts of the location of laser probe and the laser strength on the thermal effects inside the whole tissue area.

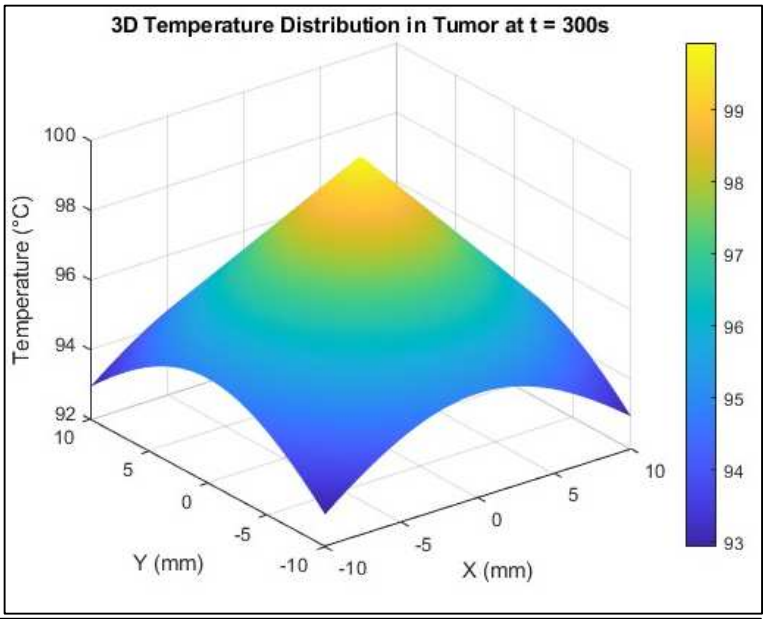


Figure 11. 3D Temperature Distribution.

4.0 Discussion

The findings of this study became significant in giving information on how laser parameters in Laser-Induced Thermotherapy (LITT) in treating breast cancer can be optimized. Computational models permitted optimal values of laser power (10 W) and exposure time (90 seconds) to be found that make an optimum compromise between maximum tumor ablation and sparing of normal tissue. The results of this study agree with prior publications that point to the values of the power of laser and exposure durations when the goal of a successful treatment and the prevention of the excessive thermal effects on the surrounding tissues can be reached. Also, application of multi-objective optimization problem, e.g. genetic algorithms yielded a Pareto set of optimal solutions which trade-off between efficacy versus safety. There are significant areas that one would consider doing better research on, though the results are promising because of among other factors, the simplified assumptions about the properties of tissues and the non-experimental character of the findings. The computations can be justified to enhance the treatment process by means of validation of the in vivo or in vitro experiments, reconciliation of dynamic tissue properties, and investigations of real time feedback systems amongst others in the future. On the whole, the given study can be considered one of the steps to more accurate and individual laser therapy on breast cancer, which may lead to the positive outcomes of treatment and the decrease of preconditions producing treatment complications.

5.0 Limitations of the Study

This study has several limitations that should be acknowledged. First, the proposed model is based on computational simulation and has not yet been validated through in vitro, ex vivo, animal, or clinical experiments. Therefore, although the results provide useful theoretical guidance, direct clinical application requires further experimental confirmation.

Second, the breast tissue geometry used in the simulation was idealized and may not fully represent the complex anatomical variability of real patients. Actual breast tissue contains heterogeneous regions such as fat, glandular tissue, blood vessels, connective tissue, and irregular tumor boundaries, which may influence laser absorption and heat diffusion.

Third, some tissue properties were assumed to be constant or simplified during simulation. In reality, thermal conductivity, blood perfusion, optical absorption, scattering coefficient, and specific heat may change dynamically with temperature, coagulation, vaporization, and tissue dehydration. These dynamic changes can affect the final ablation zone and safety margin.

Fourth, the model did not fully incorporate real-time physiological effects such as blood perfusion variation, immune response, tissue swelling, vapor bubble formation, and heat loss due to vascular cooling. These factors may alter the temperature distribution during actual LITT treatment.

Fifth, the optimization was limited to selected laser powers, exposure times, and probe depths. A wider parameter range, additional wavelengths, multiple probe arrangements, and different tumor sizes or shapes may produce different optimal settings.

Finally, the study does not include real-time image-guided feedback, such as MRI thermometry or ultrasound monitoring, which is often important for clinical LITT procedures. Future work should integrate patient-specific imaging, real-time thermal monitoring, and experimental validation to improve the accuracy, adaptability, and clinical relevance of the proposed optimization framework.

6.0 Conclusion

This work shows that a computational framework can be developed to optimize Laser parameters used in Laser-Induced Thermotherapy (LITT) used in localized treatment of breast cancer, in order to maximize ablation of the tumor, and reduce collateral damage to normal tissue. We found that the best compromise was an optimal laser power of 10 W and exposure time of 90 seconds which yielded the best results in tumor destruction and healthy tissue preservation. Moreover, laser probe depth was rather influential on treatment outcomes, and the depth of 10 mm showed the best results on deep tumors. Multi-objective optimization made it possible to identify optimal parameters of treatment, and made simulations more precise, providing personalized treatment plans. These findings have important clinical implications, offering a pathway to more precise and safe breast cancer treatments using LITT. However, further experimental validation and real-time feedback integration are needed to enhance the effectiveness and adaptability of this approach in clinical practice.

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Author Contributions

Asif Nawaz and Ghulam Saddiq are responsible for writing and experimentation validation. Waheed Nawaz and Saeed Ul Islam evaluate the technical and interference of the system. All authors reviewed the manuscript.

Data Availability:
The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations:
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Not applicable. No human and/or animal studies have been executed.

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The authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript.

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