4th URSI AT-RASC, Gran Canaria, 19-24 May 2024

A preliminary study of the assessment of the cosmetic outcome of the breast after microwave ablation

Maria C. T. Gonçalves* (1), Emily Porter (2), and Raquel C. Conceição (1)
(1) Instituto de Biofísica e Engenharia Biomédica, Faculdade de Ciências, Universidade de Lisboa, Campo Grande, 1749-016, Lisboa, Portugal (2) Department of Biomedical Engineering, McGill University, 1001 Decarie Blvd, Block E, Montreal, Quebec, H4A 3J1 Canada

Abstract

Breast cancer patients struggle with psychological trauma related to body image issues linked to the required treatment. Thus, minimally invasive treatment modalities, such as microwave ablation, have been gaining attention. Additionally, personalized pre-treatment simulations that allow assessing the cosmetic outcome of the ablation can help reduce associated trauma. The aim of this paper is to propose a framework to study the cosmetic outcome of the breast following microwave ablation. This framework can easily be adapted to reflect the future knowledge about the mechanical properties of breast tissues and their dependence on temperature.

1. Introduction

According to the latest statistics from the Global Cancer Observatory, breast cancer sets the record for new diagnosed cases, with more that 2 million new diagnoses in 2022 [1]. Treatment modalities vary depending on cancer stage at diagnosis, but surgery is part of the primary treatment regimen for the majority of patients [2]. This treatment modality leads to scarring, loss of breast volume, and deformation [3][4]. In fact, most women that undergo cancer treatment suffer from psychological trauma associated with body image disturbances and dissatisfaction [5][6]. Thus, minimally invasive treatment modalities have been gaining attention. Additionally, considering that the majority of women are diagnosed with localized breast cancer – two-thirds of diagnoses in the US – localized treatment modalities could have an increasing significant role in breast cancer treatment [7].

Microwave ablation is a localized and minimally invasive treatment modality in which a needle delivers microwave energy directly into the tumor. Yang et al. [8] report an excellent cosmetic outcome after microwave ablation in 88.0% of patients, good in 10.4%, and acceptable in 1.6% (attributed to the scar left by the ablation needle). Besides the development of minimally invasive treatment modalities, personalized pre-treatment simulations that consider the tissues' behavior to treatment could improve the patient's physical and mental health. Godden et al. [9] reported that women who viewed their personalized 3D simulation of likely cosmetic outcome after breast-conserving surgery were more confident going into surgery than those who saw examples of 2D photographs of other women.

The mechanical properties of breast tissues are essential to assess the cosmetic outcome of microwave ablation. The elastic modulus (Young's modulus, E) is the most used modulus to describe the stiffness of biological tissues but encompasses a wide range of values. For example, the reported Young's moduli vary from 0.41 ± 0.10 kPa to 23.54 ± 4.03 kPa and 0.90 ± 0.18 kPa to 26.62 ± 4.48 kPa for fat and fibroglandular tissue, respectively [10][11]. Regarding the temperature-dependence of mechanical properties, there are studies of *ex vivo* soft biological tissues, such as bovine muscle [12], porcine brain [13] and skin [14], and canine and bovine liver [15]. Although it is known that tissues stiffen due to ablation [16], there are no studies, to the best of the authors' knowledge, conducted on breast tissue that quantify the change in mechanical properties during the procedure.

The aim of this work is to present a framework we developed to assess the cosmetic outcome of microwave ablation considering the temperature-dependent mechanical properties of breast tissues. The paper is organized as follows: Introduction, the Methods followed to obtain the Results, the Discussion and Conclusion.

2. Methods

We developed a simulation pipeline to assess the cosmetic outcome of the breast after microwave ablation by analyzing the effect of gravity on the breast before and after ablation.

The simulations ran in COMSOL Multiphysics using the Electromagnetic Waves, Bioheat Transfer and Solid Mechanics modules. We simulated microwave ablation on the geometry represented in Figure 1 with a duration of 10 min, input power of 10 W, at 2.45 GHz. The simulated geometry is in 2D and includes a skin layer surrounding the breast tissue, a tumor, and the ablation needle. With this geometry, it was possible to evaluate which breast layers would be affected by the ablation.

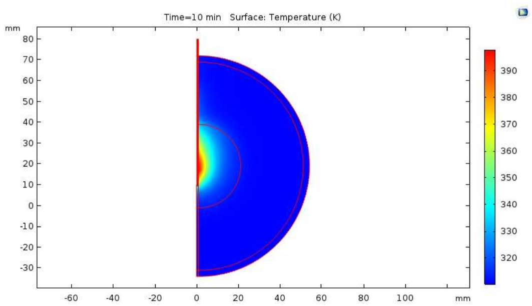

Figure 1. Geometry used in COMSOL to simulate microwave ablation: the tumor is the inner most semicircle and is surrounded by a breast layer and then a skin layer; the ablation needle corresponds to the red rectangle. Its tip was placed at the point (0.0, 10.5) mm, which corresponds to the center of the tumor. The temperature distribution of the tissues after ablation is visible.

We imported the temperature distribution after microwave ablation into a more realistic breast geometry to perform the mechanical simulations. The geometry was adjusted considering the ablation zone and the ablation needle area, which we simulated as scar tissue since there are no temperature values in the area occupied by ablation needle in the ablation simulations. Figure 2 shows the geometry used in these simulations. We applied the gravity acceleration on the whole geometry and fixed the left and bottom boundaries.

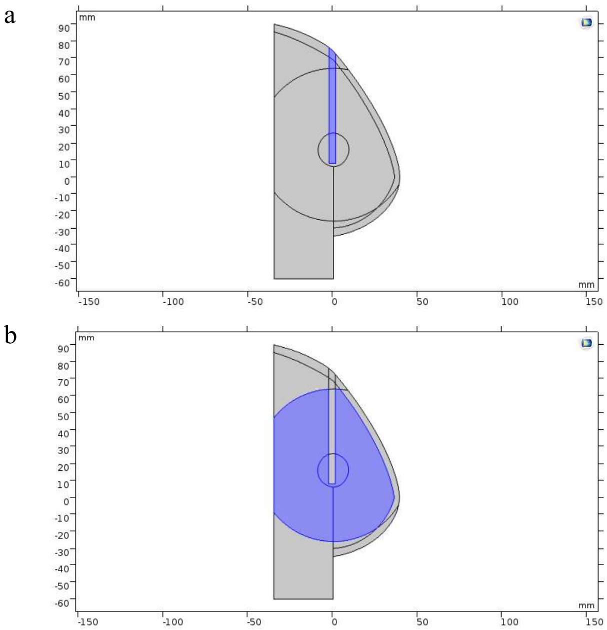

Figure 2. Geometry used to simulate the effect of the gravity on the ablated breast. a) The scar tissue was added to model the area occupied by the ablation needle during the procedure. b) The blue represents the area that was affected by the ablation, i.e. the area that must be modeled with temperature-dependent mechanical properties.

We adapted the temperature dependence of the mechanical properties of fat, fibroglandular tissue, and tumor (the areas affected by the ablation) from the magnitude of the complex modulus (|E*|) obtained from canine liver samples prepared with double immersion boiling (the samples were immersed in a bath of distilled water until reaching 90 ºC; then, they were removed from that bath and immersed in another bath of room temperature distilled water) [15]. Although these properties are not from human tissue, this was the only data of mechanical properties of soft biological tissue we found that included information up to 90 ºC. We used the same proportion reported between each value and the initial value (at around 37 ºC) and adjusted the modulus to the corresponding tissue. Figure 3 shows the trend of the temperature dependence of the mechanical properties used in this work.

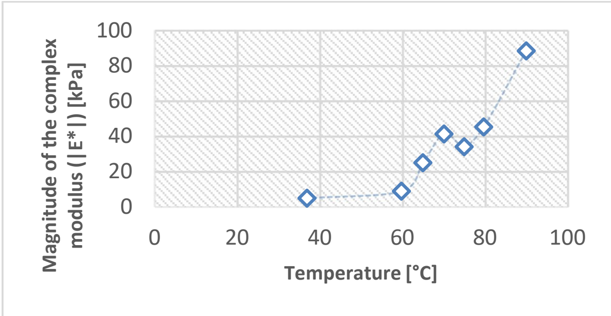

Figure 3. Magnitude of the complex modulus (|E*|) obtained from canine liver samples prepared with double immersion boiling as a function of temperature (adapted from [15]).

Table 1 lists the parameters used in the simulations to model fat, fibroglandular tissue, skin, a tumor, and scar tissue.

Table 1. Parameters used in the simulations to model fat, fibroglandular tissue (Fg), skin, a tumor, and scar tissue.

	Fat	Fg	Skin	Tumor	Scar
Density (kg/m^3)	932.00 [17]	1066.00 [17]	911 [18]	1049.75 [17]	1070.00
Young's modulus (kPa)	2.70	3.70	56.30 [19]	270.00 [20]	100.00 [21]
Poisson's ratio	0.495 [22]				
Relative permittivity	5.15 [18]	57.20 [18]	38.00 [18]	57.00 [23]	-
Relative permeability	1	1	1	1	-
Electrical conductivity (S/m)	0.137 [18]	1.970 [18]	1.460 [18]	3.000 [23]	-
Heat capacity at constant pressure (J/kg/ºC)	2220 [17]	3398 [17]	3391 [18]	3610 [17]	-
Thermal conductivity (W/m/K)	0.171 [17]	0.328 [17]	0.370 [18]	0.511 [17]	-

We used 2.60 S/m and 2.03 S/m for the relative permittivity of the catheter and the dielectric that compose the ablation needle, respectively. We simulated the blood at 37 ºC, with a specific heat 3639 J/(kg*K), a perfusion rate of 3.6×10^{-3} s^{-1} and a density of 1103 kg/m^3 [23]. We obtained the Young's modulus of fat and fibroglandular tissue from ultrasound elastography exams analyzed within our research group. Regarding the density of scar tissue, it should be denser than fibroglandular tissue [24], so we chose 1070.00 kg/m^3.

3. Results

We simulated a breast with a tumor, a skin layer and fat or fibroglandular tissue. Here, we present the results of the breast containing fat tissue. Figure 4 shows the interpolation used to represent the temperature dependence of the mechanical properties of fat tissue.

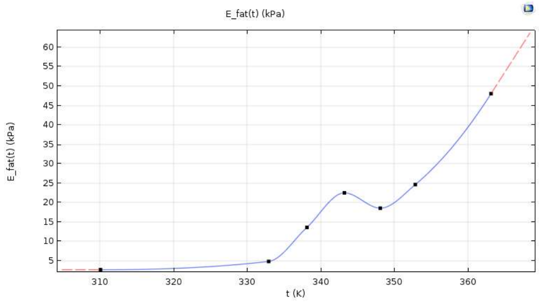

Figure 4. Interpolation used to represent the temperature dependence of the mechanical properties of fat tissue.

We attributed the temperature-dependent mechanical properties to the tissues affected by the ablation (fat, fibroglandular tissue, and tumor, as represented in Figure 2 b). The interpolations allow us to compare the deformation caused by gravity on the breast before and after ablation. Figure 5 shows the a) pre- and b) post-ablation distribution of the Young's modulus on the modeled breast, and the deformation caused by the gravity: the minimum displacement (0.00 mm at the fixed boundaries) and the maximum displacement of 9.65 mm pre-ablation and 9.25 mm post-ablation.

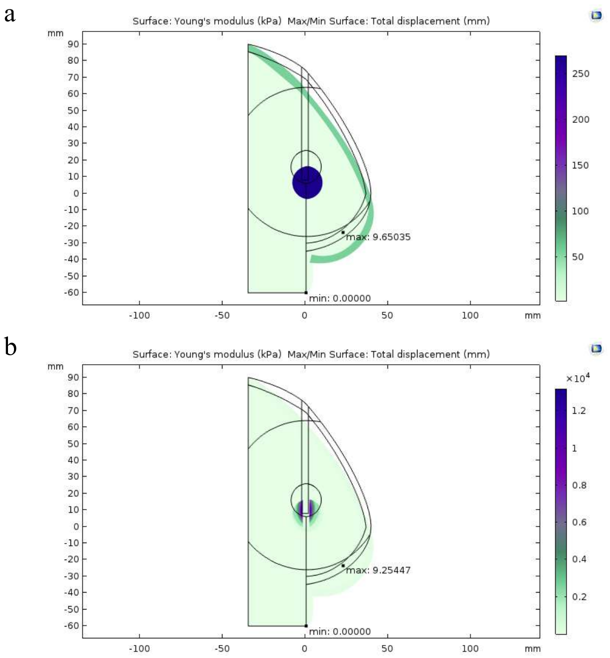

Figure 5. a) Pre- and b) post- ablation distribution of the Young's modulus of the breast composed of a tumor, fat tissue and skin. The post-ablation simulation also includes scar tissue. It is also possible to see the deformation caused by gravity and the corresponding minimum and maximum displacement.

4. Discussion

We propose a framework to assess the cosmetic outcome of microwave ablation performed on the breast. In this work, we compare the deformation caused by gravity on a pre- and post-ablated breast.

Although the mechanical properties we used were not obtained from human tissue, they show the same trend, i.e., post-ablated tissue is stiffer than pre-ablated tissue. Studies conducted on animal soft tissues show that the mechanical properties are stable or decrease for temperatures up to ~60 ºC, followed by an increase until reaching 65 ºC [12][13]. For temperatures higher than 65 ºC, there are few studies available. Kiss et al. [15] report the magnitude of the real part of the complex modulus (|E*|) – the real part of the complex modulus represents the storage modulus, which is related to the elastic component of a viscoelastic material, such as biological tissue [25] – of canine and porcine liver samples measured from around 40 ºC up to 90 ºC. With the mechanical properties adapted from [15], we verified that our simulations show that the post-ablation breast sags less, when compared to the breast before ablation. This behavior is what we expected since ablated tissues are stiffer than unablated tissue.

5. Conclusion

The proposed simulation framework corresponds to a first step in developing an application to assess the cosmetic outcome of microwave ablation. This application can help decrease the psychological trauma related to body image issues patients suffer from after cancer treatment. At this stage, the application shows the effect of gravity on pre- and post-ablated breast. Once knowledge of the mechanical properties of breast tissues increases, we can easily update the framework to incorporate the new information. We can also extend the framework to 3D and include other models that require mechanical information, such as the wound healing of the hole left by the ablation needle.

6. Acknowledgements

This work was funded by Fundação para a Ciência e Tecnologia (FCT) under the fellowship 2021.07228.BD and under the Strategic Program UIDB/00645/2020 (https://doi.org/10.54499/UIDB/00645/2020).

References

[1] International Agency for Research on Cancer - World Health Organization, "GLOBOCAN 2022: Estimated Cancer Incidence, Mortality and Prevalence Worldwide in 2022 - Cancer Fact Sheets." https://gco.iarc.who.int/media/globocan/factsheets/cancers/20-breast-fact-sheet.pdf.

[2] Cancer Research UK, "Breast cancer statistics." https://www.cancerresearchuk.org/health-professional/cancer-statistics/statistics-by-cancer-type/breast-cancer#heading-Six.

[3] B. O. Anderson, R. Masetti, and M. J. Silverstein, "Oncoplastic approaches to partial mastectomy: an overview of volume-displacement techniques," Lancet Oncol., vol. 6, no. 3, pp. 145–157, 2005, doi: https://doi.org/10.1016/S1470-2045(05)01765-1.

[4] R. A. Cochrane, P. Valasiadou, A. R. M. Wilson, S. K. Al-Ghazal, and R. D. Macmillan, "Cosmesis and satisfaction after breast-conserving surgery correlates with the percentage of breast volume excised.," Br. J. Surg., vol. 90, no. 12, pp. 1505–1509, Dec. 2003, doi: 10.1002/bjs.4344.

[5] M. Thakur, R. Sharma, A. K. Mishra, K. Singh, and S. K. Kar, "Psychological distress and body image disturbances after modified radical mastectomy among breast cancer survivors: A cross-sectional study from a tertiary care centre in North India," Lancet Reg. Heal. - Southeast Asia, vol. 7, 2022, doi: 10.1016/j.lansea.2022.100077.

[6] T. S. R. Guedes et al., "Body Image of Women Submitted to Breast Cancer Treatment," Asian Pacific J. Cancer Prev., vol. 19, no. 6, pp. 1487–1493, 2018, doi: 10.22034/apjcp.2018.19.6.1487.

[7] American Cancer Society, "Breast Cancer Facts & Figures 2022-2024," American Cancer Society, Inc. 2022, [Online]. Available: https://www.cancer.org/research/cancer-facts-statistics/breast-cancer-facts-figures.html.

[8] Q. Yang et al., "Ultrasound-guided percutaneous microwave ablation for 755 benign breast lesions: a prospective multicenter study.," Eur. Radiol., vol. 30, no. 9, pp. 5029–5038, Sep. 2020, doi: 10.1007/s00330-020-06868-9.

[9] A. R. Godden et al., "Three-dimensional simulation of aesthetic outcome from breast-conserving surgery compared with viewing photographs or standard care: randomized clinical trial.," Br. J. Surg., vol. 108, no. 10, pp. 1181–1188, Oct. 2021, doi: 10.1093/bjs/znab217.

[10] J. Chen et al., "Non compressive MR elastography of breasts," 2013, [Online]. Available: https://archive.ismrm.org/2013/1736.html.

[11] E. E. W. Van Houten, M. M. Doyley, F. E. Kennedy, J. B. Weaver, and K. D. Paulsen, "Initial in vivo experience with steady-state subzone-based MR elastography of the human breast," J. Magn. Reson. Imaging, vol. 17, no. 1, pp. 72–85, 2003, doi: https://doi.org/10.1002/jmri.10232.

[12] E. Sapin-de Brosses, J.-L. Gennisson, M. Pernot, M. Fink, and M. Tanter, "Temperature dependence of the shear modulus of soft tissues assessed by ultrasound," Phys. Med. Biol., vol. 55, no. 6, p. 1701, 2010, doi: 10.1088/0031-9155/55/6/011.

[13] Y.-L. Liu, G.-Y. Li, P. He, Z.-Q. Mao, and Y. Cao, "Temperature-dependent elastic properties of brain tissues measured with the shear wave elastography method," J. Mech. Behav. Biomed. Mater., vol. 65, pp. 652–656, Jan. 2017, doi: 10.1016/j.jmbbm.2016.09.026.

[14] F. Xu, K. Seffen, and T. Lu, "Temperature-Dependent Mechanical Behaviors of Skin Tissue," IAENG Int. J. Comput. Sci., vol. 35, Jan. 2008, doi: 10.1002/9780470382776.ch1.

[15] M. Z. Kiss, M. J. Daniels, and T. Varghese, "Investigation of temperature-dependent viscoelastic properties of thermal lesions in ex vivo animal liver tissue," J. Biomech., vol. 42, no. 8, pp. 959–966, May 2009, doi: 10.1016/j.jbiomech.2009.03.002.

[16] Z. Zhou et al., "A survey of ultrasound elastography approaches to percutaneous ablation monitoring," Proc. Inst. Mech. Eng. Part H J. Eng. Med., vol. 228, no. 10, pp. 1069–1082, Oct. 2014, doi: 10.1177/0954411914554438.

[17] J. S. Camilleri et al., "Review of Thermal and Physiological Properties of Human Breast Tissue," Sensors, vol. 22, no. 10, pp. 1–29, 2022, doi: 10.3390/s22103894.

[18] Foundation for Research on Information Technologies in Society, "IT'IS Foundation." https://itis.swiss/virtual-population/tissue-properties/database (accessed Jan. 12, 2021).

[19] N. Briot, G. Chagnon, N. Connesson, and Y. Payan, "In vivo measurement of breast tissues stiffness using a light aspiration device," Clin. Biomech., vol. 99, p. 105743, Oct. 2022, doi: 10.1016/j.clinbiomech.2022.105743.

[20] M. K. Metwally, S. H. El-Gohary, S. M. Han, K. M. Byun, and T. S. Kim, "Influence of the anisotropic mechanical properties of the breast cancer on photoacoustic imaging," Proc. 7th Cairo Int. Biomed. Eng. Conf. CIBEC 2014, no. December, pp. 34–38, 2015, doi: 10.1109/CIBEC.2014.7020958.

[21] M. M. Ibrahim et al., "A novel immune competent murine hypertrophic scar contracture model: A tool to elucidate disease mechanism and develop new therapies," Wound Repair Regen., vol. 22, no. 6, pp. 755–764, Nov. 2014, doi: 10.1111/wrr.12238.

[22] D. W. Park, "Ultrasound Shear Wave Simulation of Breast Tumor Using Nonlinear Tissue Elasticity," Comput. Math. Methods Med., vol. 2016, p. 2541325, 2016, doi: 10.1155/2016/2541325.

[23] R. Ortega-Palacios et al., "Feasibility of Using a Novel 2.45 GHz Double Short Distance Slot Coaxial Antenna for Minimally Invasive Cancer Breast Microwave Ablation Therapy: Computational Model, Phantom, and In Vivo Swine Experimentation," J. Healthc. Eng., vol. 2018, pp. 1–10, 2018, doi: 10.1155/2018/5806753.

[24] M. Xue and C. J. Jackson, "Extracellular Matrix Reorganization During Wound Healing and Its Impact on Abnormal Scarring," Adv. Wound Care, vol. 4, no. 3, pp. 119–136, Mar. 2015, doi: 10.1089/wound.2013.0485.

[25] L. Bianchi, F. Cavarzan, L. Ciampitti, M. Cremonesi, F. Grilli, and P. Saccomandi, "Thermophysical and mechanical properties of biological tissues as a function of temperature: a systematic literature review," Int. J. Hyperth., vol. 39, no. 1, pp. 297–340, 2022, doi: 10.1080/02656736.2022.2028908.