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Preliminary Tests of Axillary Microwave Imaging with Healthy Volunteers

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Abstract

Breast cancer is the most common type of cancer in women and its early diagnosis is essential to guarantee a good prognosis. The axillary lymph nodes can be affected by breast cancer and the existence or not of metastases in these structures is decisive for breast cancer staging. Microwave Imaging (MWI) has been studied to aid axillary lymph node diagnosis and overcome sensitivity and specificity limitations reported in other imaging modalities. In this study, we performed axillary MWI examinations with female healthy volunteers using our MWI prototype - being the first study of the axillary area to be carried out with volunteers worldwide. The shape variability of the axillary region was analysed in 22 volunteers, showing the importance of selecting appropriate reference points to position the volunteers, in preparation for patient studies.

1 Introduction

Breast cancer affected 2.29 million women worldwide, only in 2022, making it the second most common cancer worldwide [1]. In more advanced stages of cancer, the cancer cells can be drained to neighbouring lymph nodes, mainly the Axillary Lymph Nodes (ALNs). In those cases, the survival rate can decrease about 10%. Thus, the number of affected ALNs is considered for breast cancer staging, impacting the therapeutic decisions. The current diagnosis of ALNs can be performed using imaging modalities but these have limitations in terms of sensitivity and specificity [2]. Currently, the most accurate diagnosis technique is the Sentinel Lymph Node Biopsy (SLNB), which is an invasive and costly procedure [3].

Microwave Imaging (MWI) has shown promising results for early diagnosis of breast cancer [4] and has been recently studied to aid ALN diagnosis [5, 6]. MWI is a non-invasive technique, it is low-cost and uses low-power, making it suitable for breast cancer screening and staging.

We are developing a two-in-one MWI prototype to image both the breast and the axillary region. In this paper, we present a preliminary study of axillary microwave imaging with female volunteers. Radar-based MWI is used, where an electromagnetic pulse radiated by each antenna illuminates the axillary region and the backscattered signals are recorded and used to reconstruct the image. Higher magnitude regions of the image correspond to the presence of a dielectric contrast in the microwave frequencies band. Besides presenting our prototype and measurement data, we analyse the variability of axillary region contours examined for 22 volunteers and highlight the main challenges moving forward to patient studies.

2 Methodology

2.1 Experimental prototype

The axillary MWI prototype has 9 planar monopole antennas [7] operating in the frequency band from 2 to 4 GHz in air, in a monostatic configuration. The antennas are placed in a planar configuration, as determined in [8], on a 3D-printed planar platform, as observed in Figure 1.

The microwave signals are generated and recorded by a 2-port E5063A ENA Vector Network Analyser (Keysight®), which is connected to a 11713D Attenuator/Switch Driver (Keysight®) which controls a U7110B Multiport Electromechanical Switch (Keysight®) and selects which of the 9 antennas is operating at each time. The acquisition is performed automatically using a script developed with MATLAB® 2020a and SCPI commands. Before and after each volunteer measurements, a free-space measurement is performed to remove the antenna response and for quality control.

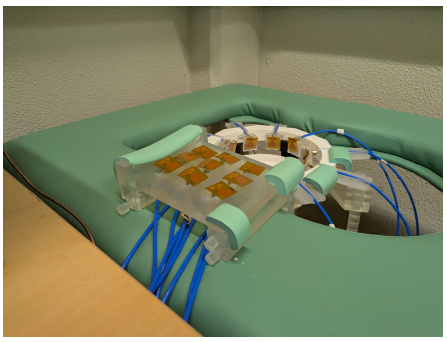


Figure 1. Axillary microwave imaging prototype in examination bed.

2.2 Data acquisition

The axillary MWI prototype was tested with 22 female volunteers, in the context of a study which was approved by the Ethics Committee of Faculdade de Ciências, Universidade de Lisboa (CEC/36/2023). Table 1 shows the statistics of the volunteers group. At the end of the acquisition, the volunteers filled in a quality questionnaire to assess the prototype in terms of comfort and duration of the exam.

Table 1. Statistics of the volunteers group. BMI: Body Mass Index

	Mean	**Range**	**Frequency**
Age	37.5	20 a 76	-
BMI	24.5	17.3 a 34.4	-
Breast Cup	-	-	B: 50% C: 22% D: 18% E: 5% F: 5%

Three volunteers with different morphological characteristics were selected for a more detailed analysis. The first volunteer was 27 years old, had a B cup size and a Body Mass Index (BMI) of 19.9. The second volunteer was 27 years old, with a cup size C and a BMI of 28.9. The third volunteer was 54 years old, with a cup size E and a BMI of 34.4. No information was available regarding other imaging tests nor breast density for these volunteers.

2.3 Signal processing

To perform an analysis of the contours of the axillary region, no artefact removal or image reconstruction was performed. As this is the first study of MWI with volunteers dedicated to the axillary region, this type of analysis is important to define the future steps of the technological development. The signals used for this paper's analysis were obtained from the subtraction between the measurements with the left axillary region and the free-space measurements.

The contour of the axillary region was determined considering the distance between each antenna and the skin. The antenna-to-skin distance was calculated considering the distance at which the higher reflection was recorded for each antenna. That distance was then used to draw the axillary region contour in a surface plot.

3 Results and discussion

3.1 Distance to skin variability

Figure 2 shows a box plot of the antenna-to-skin distance variation of the 9 antennas for each examined volunteer. It also shows there is a great variability in the recorded distances. Although results suggest there is a greater minimum distance for volunteers with larger breasts (larger cups), the

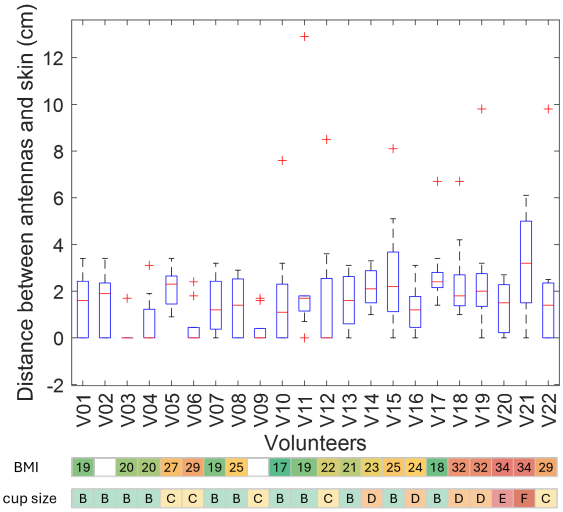


Figure 2. Distribution of distances between the antennas and the skin for each volunteer. The numbering in this figure does not correspond to volunteers 1, 2 and 3 selected for the remaining analysis.

number of cases does not allow definite conclusions to be drawn. These results can be explained by the observations made during the acquisition of MWI measurements: due to different sizes of the arms and torso, finding a standardised positioning of the patient on the axillary MWI prototype, comprising the planar platform with the 9 antennas, was challenging. Furthermore, volunteers with a larger breast volume had more difficulty correctly positioning their axillary region on the antennas planar platform, as the breast raised their torso.

This variation in antenna-to-skin distances also has an impact on the maximum intensity of skin detection in the image reconstruction, as observed in Figure 3. The maximum intensity value varies between 249 and 804 for the several volunteers. Radar MWI is not quantitative and, consequently, values are not directly comparable. However, for similar antenna-to-skin distances such a large variation in intensity would not be expected. Lower intensity values correspond to signals recorded by antennas further away from the skin and vice versa. Thus, the range of intensity values also provide insights on the variability of contours and positioning.

Figure 4 shows the representations of the axillary region contour for three selected patients. It shows the antenna-to-skin distance of the several antennas varies within and between volunteers. This is also generally observed for the remaining 19 volunteers (results not shown). This variability on antenna-to-skin has an impact on the performance of artefact removal algorithms since there is no pattern of neighbouring antennas that allows estimating the response of the skin to be removed. Thus, it is necessary to perform prototype adjustments in order to ensure standardisation of the patient's positioning, while minimising the antenna-to-

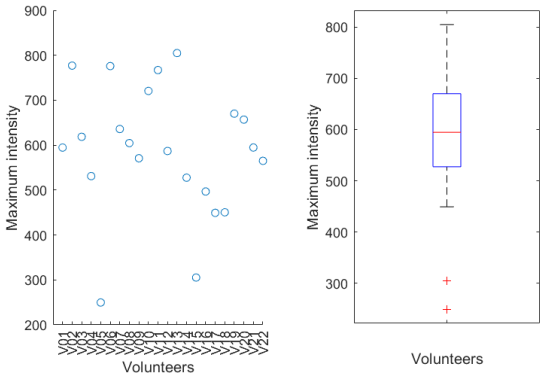
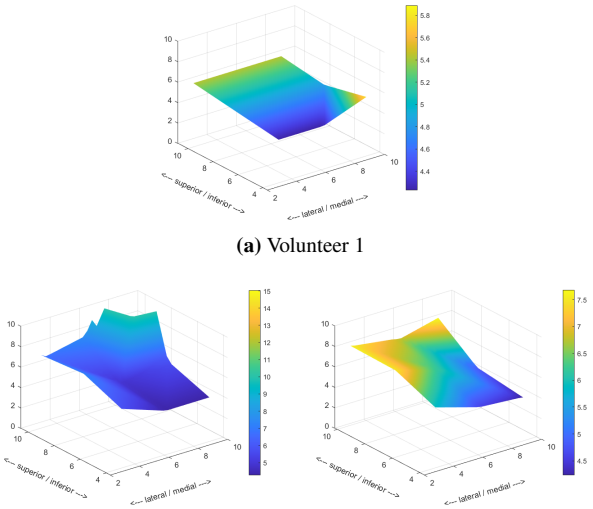


Figure 3. Distribution of the maximum image intensity value without removing artefacts for each volunteer. The numbering in this figure does not correspond to volunteers 1, 2 and 3 selected for the remaining analysis.



(a) Volunteer 1

(b) Volunteer 2 **(c)** Volunteer 3

Figure 4. Estimated axillary region contour for three volunteers. The colour scale represents the distances between the antenna and the skin in centimetres.

skin distance.

3.2 Evaluation of the exam's comfort and duration

Figures 5 and 6 summarise the results of the quality questionnaire filled in by the volunteers who participated in the study. Approximately 36% of the volunteers rated the exam as very comfortable, 45% rated it as comfortable and 18% rated it as neutral.

In terms of duration, 64% rated the exam as very quick and 36% rated it as quick. On average, the exams took 5.6 minutes, in addition to the informative presentation and signing of the informed consent for the study that preceded the exam, and completing the survey.

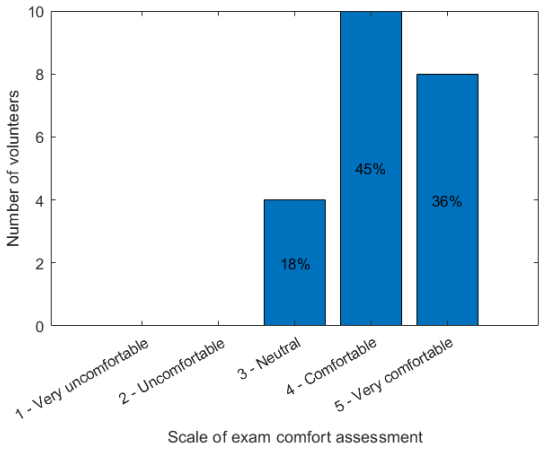


Figure 5. Bar plot of exam comfort assessment responses.

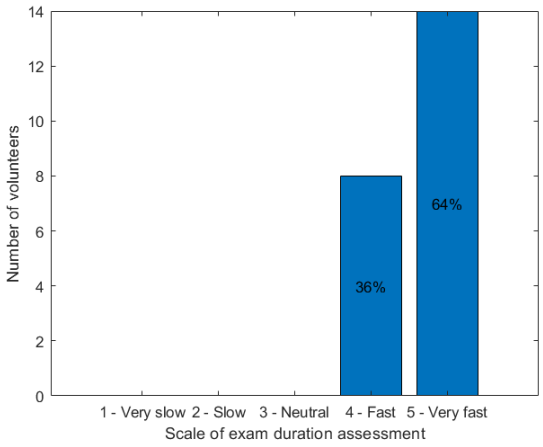


Figure 6. Bar plot of exam duration assessment responses.

4 Conclusions

This work presented a preliminary study in which healthy female volunteers were examined with the new axillary MWI prototype under development at Institute of Biophysics and Biomedical Engineering, Faculty of Sciences of the University of Lisbon.

The results show the existence of a large variability in the positioning of the axillary region on the prototype, which result in a large variability of antenna-to-skin distances. This variability limits the choice of appropriate processing algorithms, their performance and comparison of the different cases. Ensuring a minimal and consistent antenna-to-skin distance is essential to yield high-quality imaging results.

Future work includes optimising the prototype in order to minimise the positioning variability and testing with more volunteers and patients.

Acknowledgments

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