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Microwave Dielectric Contrast Imaging in a Magnetic Resonant Environment and the Effect of using Magnetic Resonant Spatial Information in Image Reconstruction

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Abstract

Microwave Tomography (MT) can determine the permittivity and conductivity of a volume of interest; it has been shown that a contrast exists between these electrical properties in healthy and malignant tissues, and MT can be used to discern the dielectric contrast image of these tissues by recovering their electrical property values. Simulation and phantom experiments of objects with known spatial locations have shown that using boundary information derived from internal structures in the imaged volume greatly increases the accuracy of the recovered property values. In practice this spatial information, which will be used for reconstructing the tissue's electrical property images, must be determined with high enough resolution to segment boundary regions and internal structures of interest. This experiment investigates the use of Magnetic Resonant Imaging (MRI) in obtaining the desired spatial information used in mesh generation for image reconstruction and provides microwave image results comparing electrical properties recovered with and without this prior spatial information.

I. Introduction

The dielectric properties of a volume of interest can be determined using MT [1]. It has been shown that using spatial information describing the internal structures of the imaging volume in the image reconstruction mesh results in increased property recovery when compared to images reconstructed without this prior spatial information [2]. This result shows that the calculated electrical property distributions, based on the measured microwave signals at the perimeter of the volume, are recovered to a higher degree of validity when using information regarding the internal structures of the imaging volume then when not, as the approximated solutions are closer to the exact solution with the prior spatial information then without. The spatial information needs to be of high enough resolution as to allow the segmentation of the volume's internal structures. Research has investigated the use of ultrasound [3,4] and computed tomography [5] in acquiring the required spatial information

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for microwave image reconstruction. Another possible method for acquiring the internal spatial information is the use of MRI; this techniques has been successfully used in near infrared (NIR) imaging [6].

We have created a microwave imaging tank that can operate in the magnetic environment of the MRI system's magnetic bore; this tank is capable of acquiring microwave data by transmitting and receiving microwave signals inside the MRI system's magnetic bore with minimal effects to both the microwave and magnetic resonance (MR) images [7]. A MR image is used to segment the internal structures of the imaged volume for use in creating a triangular element reconstruction mesh that allows the generating of microwave electrical property images. This is accomplished by applying a regularization scheme that penalizes the weighting of pixels in different regions and accentuates that of those in the same region [2].

This paper will investigate the role that MRI can play in acquiring this spatial information by providing reconstructed images of a breast-like phantom with an arbitrarily-shaped inclusion, comparing images reconstructed with and without the spatially derived mesh, showing increased efficacy in the recovered electrical property distributions, as compared to the exact solution, when reconstruction is conducted using the prior spatial information.

II. Methods

The generation of the spatially derived reconstruction mesh and dielectric property images requires the use of a microwave tomography system that can operate in the high strength magnetic field of the MRI system's magnetic bore. This system uses 16 transceiver modules for transmitting and receiving microwave signals; for a more detailed review of the Microwave Imaging System Technology (MIST) data acquisition system hardware can be found in Meaney et al 2007. The following sections highlight the microwave imaging system's illumination tank, the combined MR-microwave system, the microwave image reconstruction algorithm including the use of the MR image in forming the spatially derived reconstruction mesh and the method used for phantom creation.

A. Microwave Imaging System Illumination Tank

Figure 1 shows the 26 cm diameter microwave illumination tank which incases a 15.2 cm antenna array. The array utilizes 16 low profile monopole antennas, made of 12.54 cm of 3.58 cm diameter copper coaxial cable with a 2.54 cm exposed tip; this tip forms the active part of the antenna. Each antenna is connected to a SMA flange that allows connection of the tank to the data acquisition system; a more detailed description of the monopole antenna's composition and connections can be found in Meaney et al 2011. Connections to the antenna array are accomplished through the use 16 independent 3.58 mm diameter semi rigid coaxial cables, consisting of a copper outer conductor and a silver-plated, copper center conductor.

B. Combined Microwave MRI system

When acquiring microwave data inside the magnetic bore, it is necessary to keep the microwave data acquisition system outside of the magnetically shielded room that houses the MRI system; this is accomplished by the use of 16 SMA connectors that are attached to a bulkhead panel mounted in the wall that separates the magnetically shielded room and the data acquisition system. Figure 2a shows the Microwave Imaging data acquisition system, positioned outside of the magnetically shielded room, connected to the bulkhead adapters installed in the wall.

Positioned inside the magnetic bore, each antenna in the imaging array and its associated semi rigid cables assembly are connected in series with a flexible coaxial cable line to the SMA connector on the shielded side of the bulkhead panel. The control room side of the bulkhead is connected to the data acquisition system with flexible coaxial cable, as described above. Figure 2b and 2c show the illumination tank with antenna array inside the MR system's magnetic bore with cable assembly and the cable connections to the bulkhead inside the magnetically shielded room respectively.

The imaging volume, as seen in figure 3a, consisted of a rapid-prototyped plastic breast perimeter filled with an 88% glycerin bath surrounded by an 80% glycerin bath; the bath in the breast perimeter was chosen to mimic the electrical properties of the scattered breast. The 80% bath used to fill the tank around the breast acts as a matching layer that limits unwanted reflected signals, while resistively loading the antennas, allowing for measurable signal attenuations with antennas located in such a close proximity. Suspended in the breast phantom is a saline gel tumor-like inclusion, as seen in figure 3b.

C. Incorporating a-prior Structural Information into Microwave Image Reconstruction Algorithm

We have recently developed a multi-modality process that combines the high spatial resolution of MRI with the high specificity of the microwave tomography using so called "soft-prior (SP)" regularization [2]. The goal is to incorporate available spatial information about the shape of the boundary of each region within the object being imaged into our microwave image reconstruction algorithm through a regularization matrix, by penalizing the variation within regions that are assumed to have the same or similar dielectric properties. Based on known spatial information, each node in the reconstruction mesh is assigned with a region number.

When spatial structure of the object is available, a customized reconstruction mesh can be made. In the current study we have segmented 3 different regions of the MR image corresponding to the microwave data plane (figure 4a) to create a 2D mask shown in figure 4b. The mask was then input to our 2D mesh generating code, where the customized mesh in figure 5, composed of 3844 nodes and 7192 triangular elements was obtained and used in our reconstruction algorithm with the soft prior regularization.

D. Inclusion Creation and Electrical Properties

The gelatin inclusion consists of an 85% gelatin to 15% saline mixture by weight; upon mixing, the solution was heated to approximately 55° C in a microwave oven. The gel mixture was injected into a circular, ping-pong ball mold, and left to cool off over night in a refrigerator; the outer plastic mold layer was removed after the gel mixture cooled.

III. Results & Conclusion

Figure 6a and b show the 1300MHz reconstructed permittivity images with and without the use of the spatially derived reconstruction mesh.

In both images, with and without soft-prior regularization, the target inclusion is detected. However, the reconstructed permittivity image with the use of prior spatial information is clearly superior in terms of the location of the target inclusion, as well as the breast region. The dielectric properties of the scattered breast (88% glycerin mixture) were slightly lower than those of the background medium, and this variation is correctly detected by the use of the soft-prior algorithm. Moreover, the level of background artifact is significantly reduced in the soft-prior image.

In this study, we evaluated the role that MR can play in developing a spatially derived reconstruction technique for use in microwave imaging. Results from a breast-shaped phantom experiment showed that incorporating prior anatomical information obtained from the high-resolution MR image to our microwave reconstruction algorithm can improve the quality of the recovered electrical property distributions.

Acknowledgments

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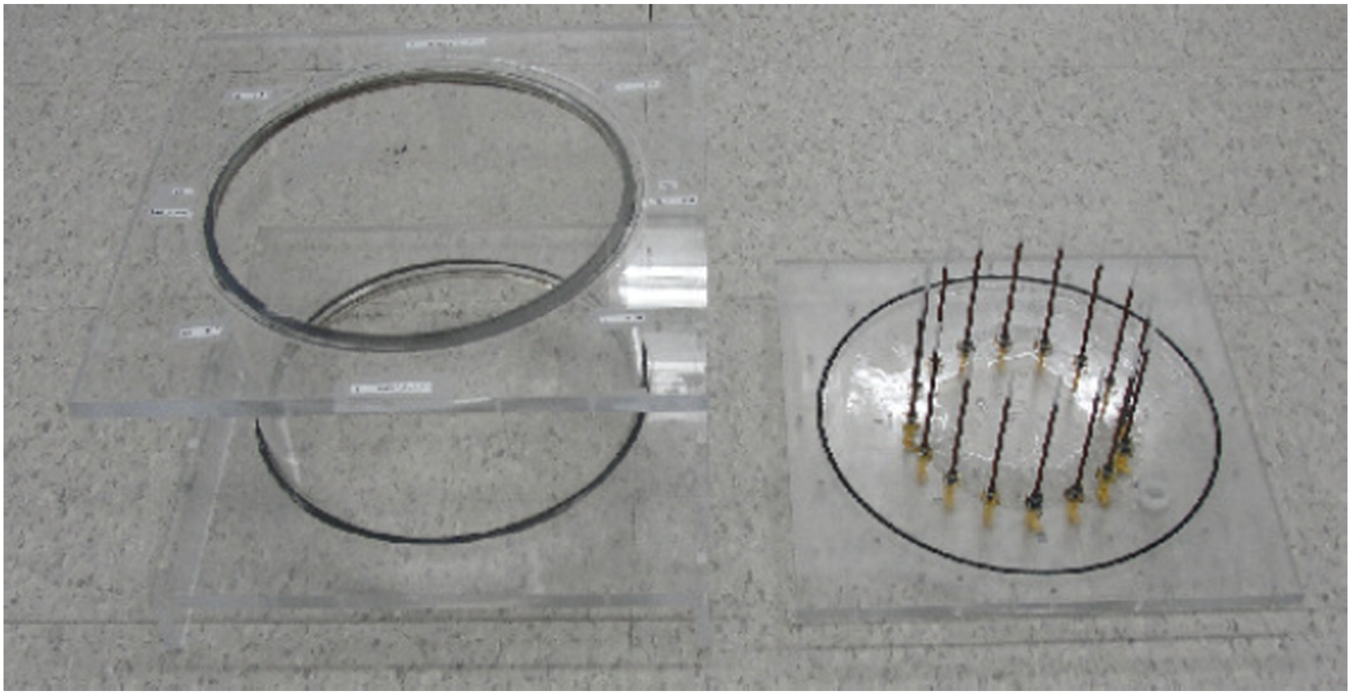


Fig. 1.
Microwave illumination tank and antenna array with exposed tips.

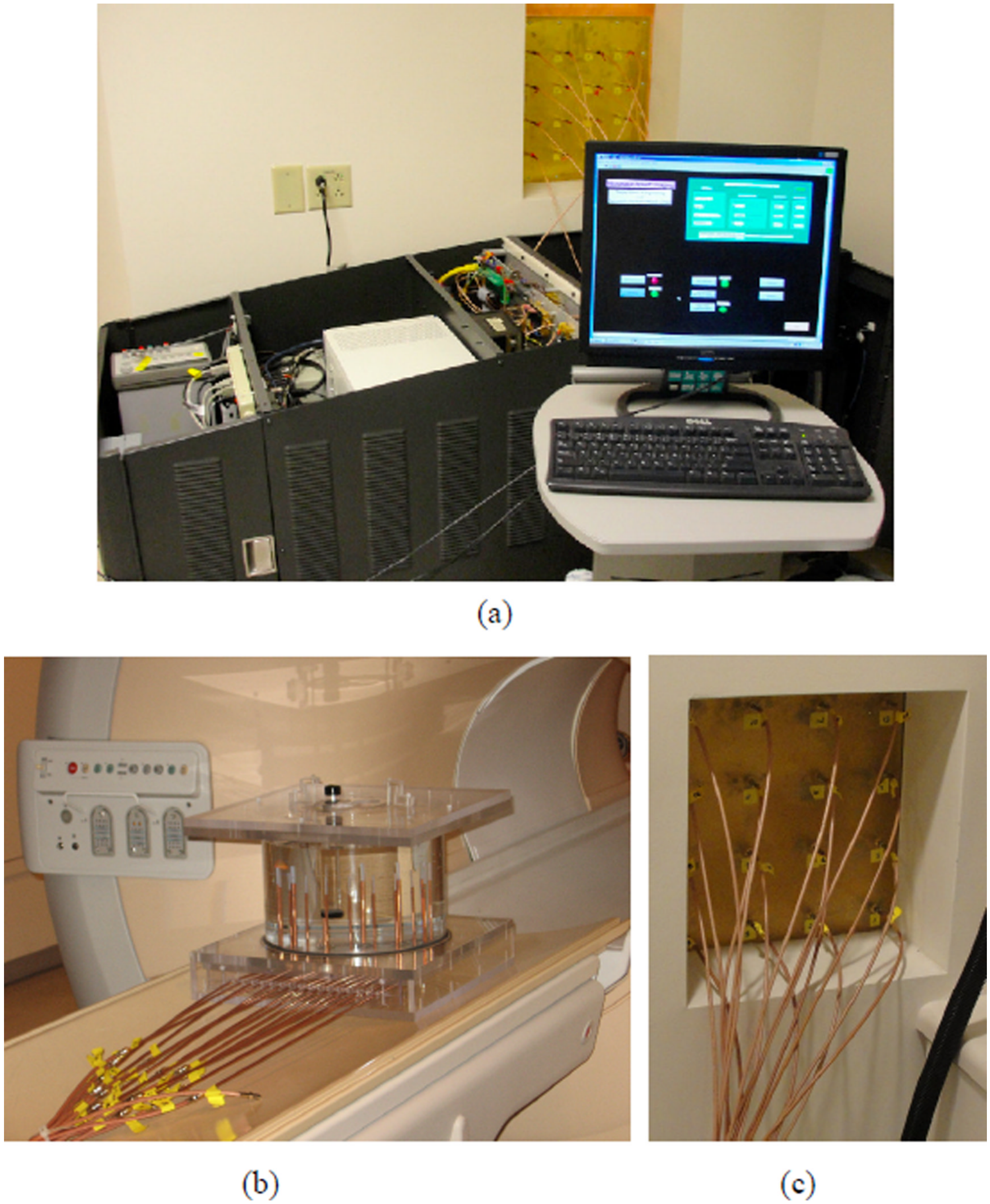
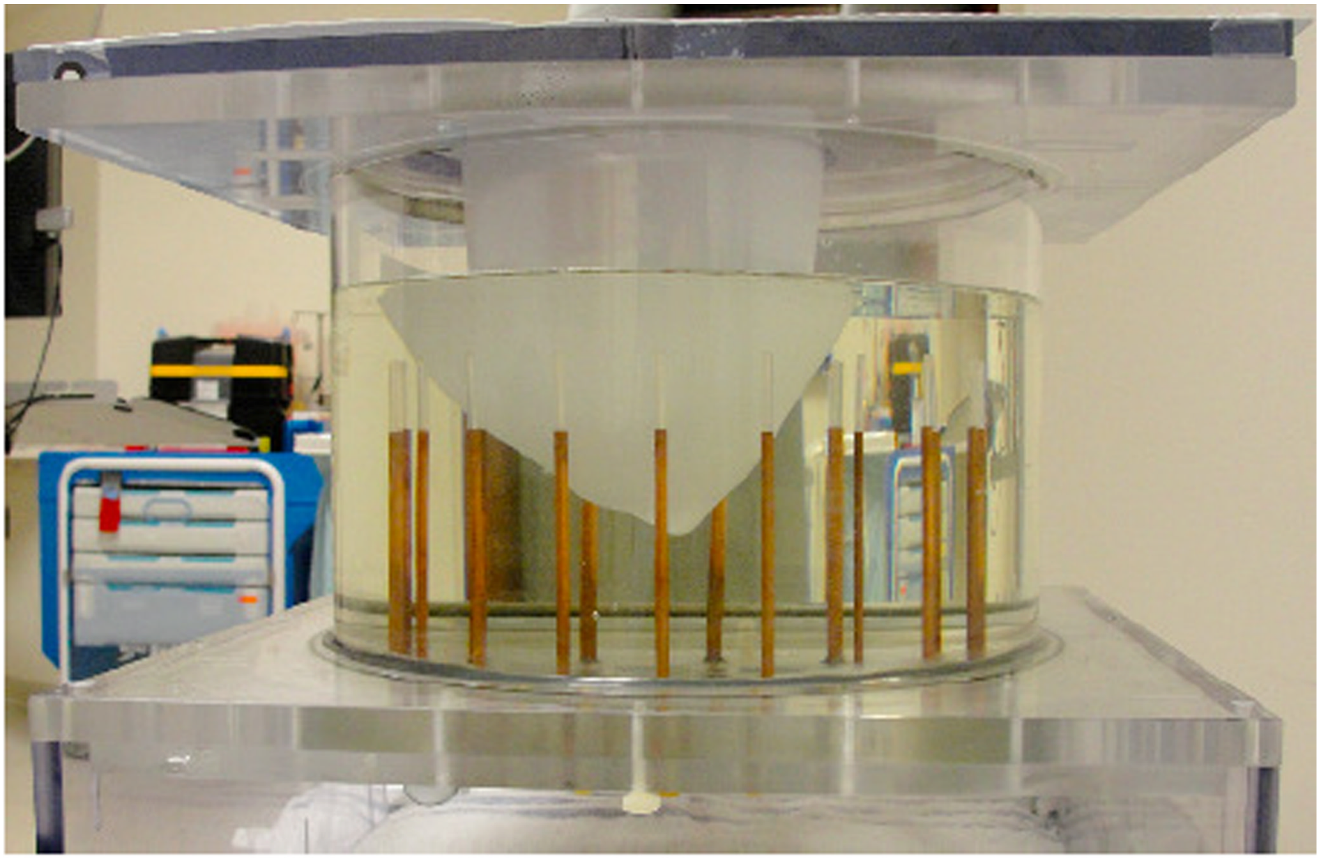


Fig. 2.
(a) Wall mounted bulkhead with 16 SMA adapters allowing connection of the tank inside the magnetically shielded room to the data acquisition system in the control room, (b) Microwave tank and antenna array in MR bore with associated connector assemblies, (c) Flexible coaxial cable connected to bulkhead adapters in the magnetically shielded room



a.

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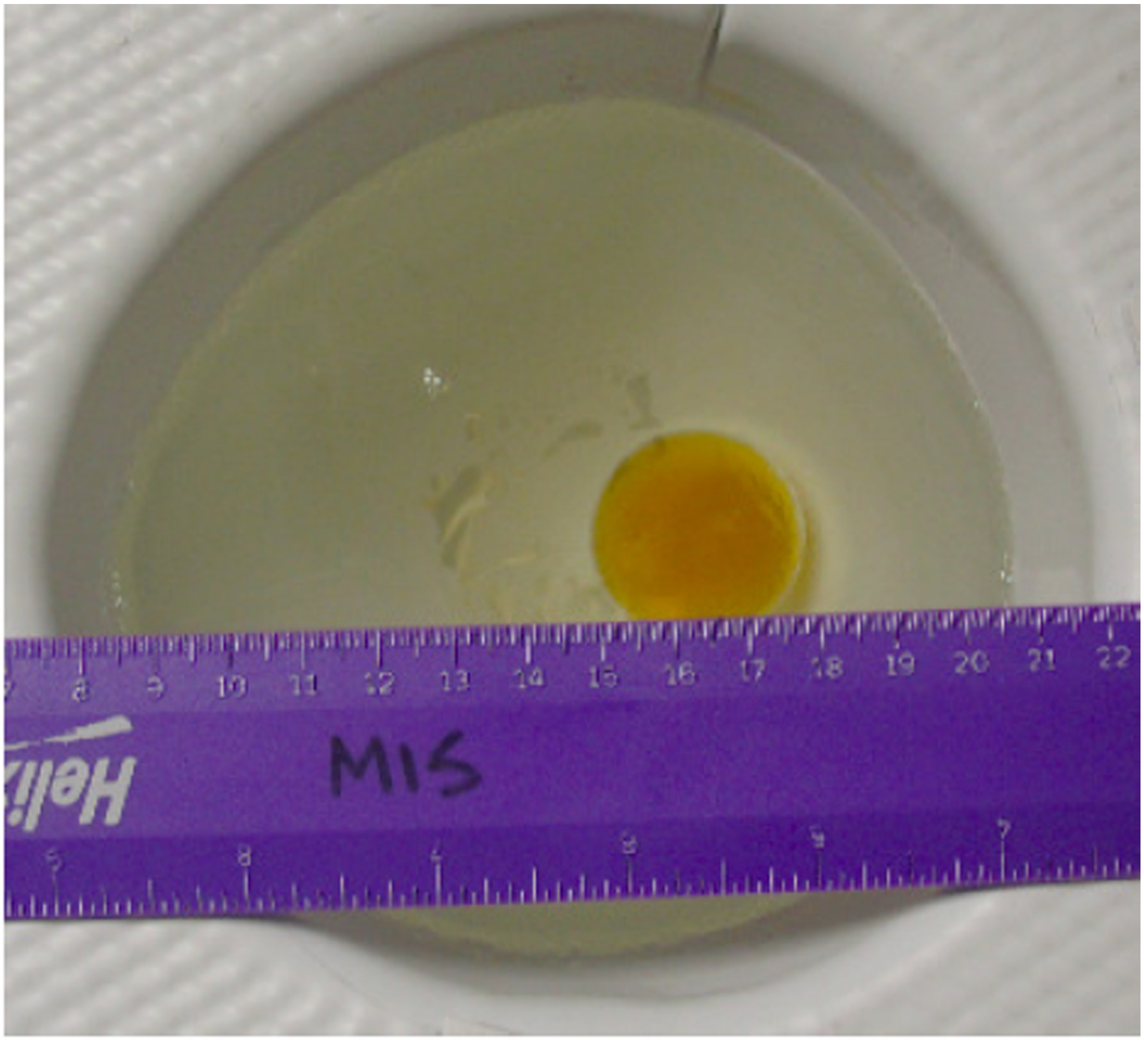
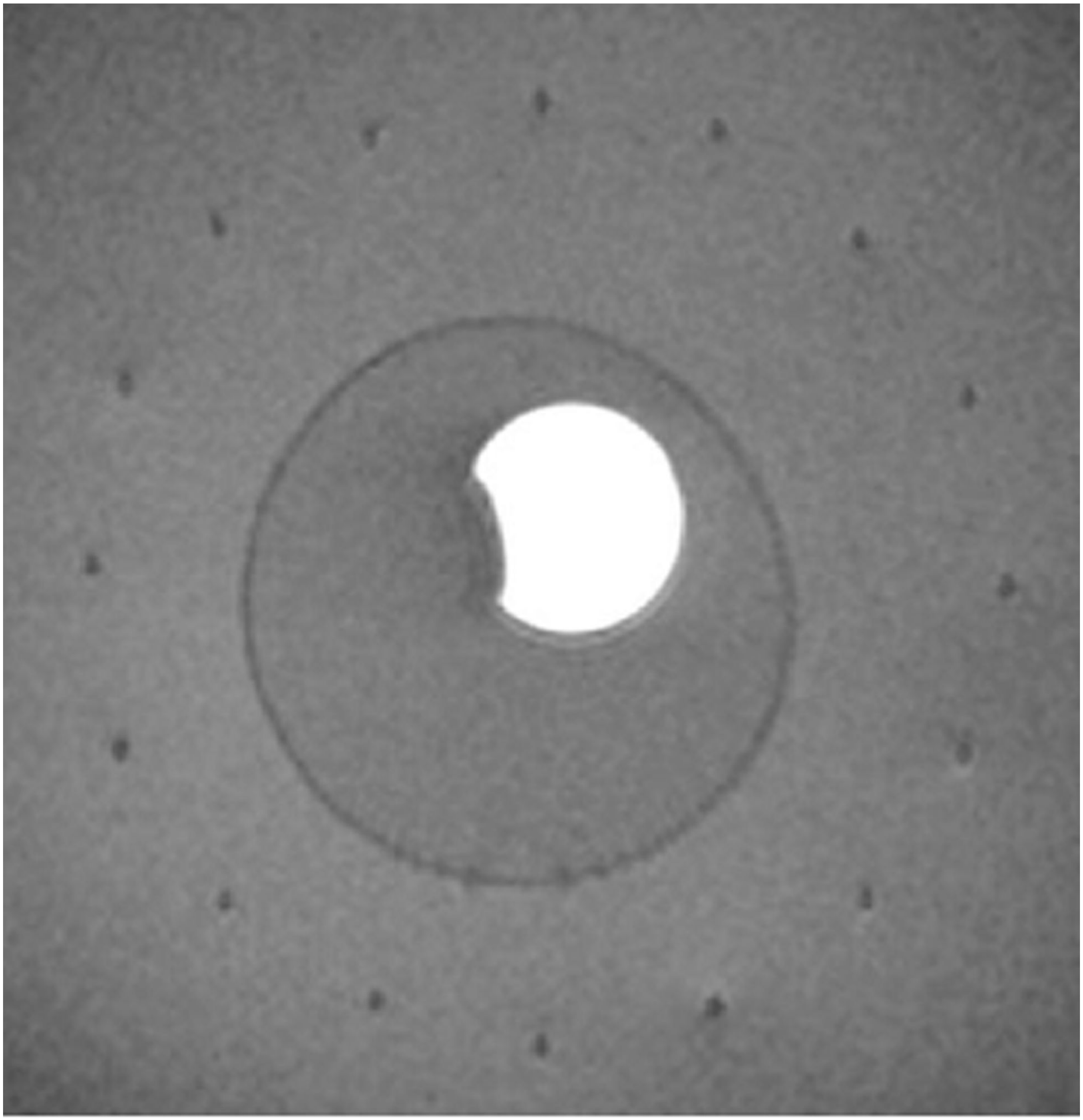


b.

Fig. 3.

a. Imaging tank and antenna array with breast perimeter submerged in associated glycerin bath.

b. Top down view looking into breast perimeter with saline gel inclusion suspended in associated breast bath.



(a)

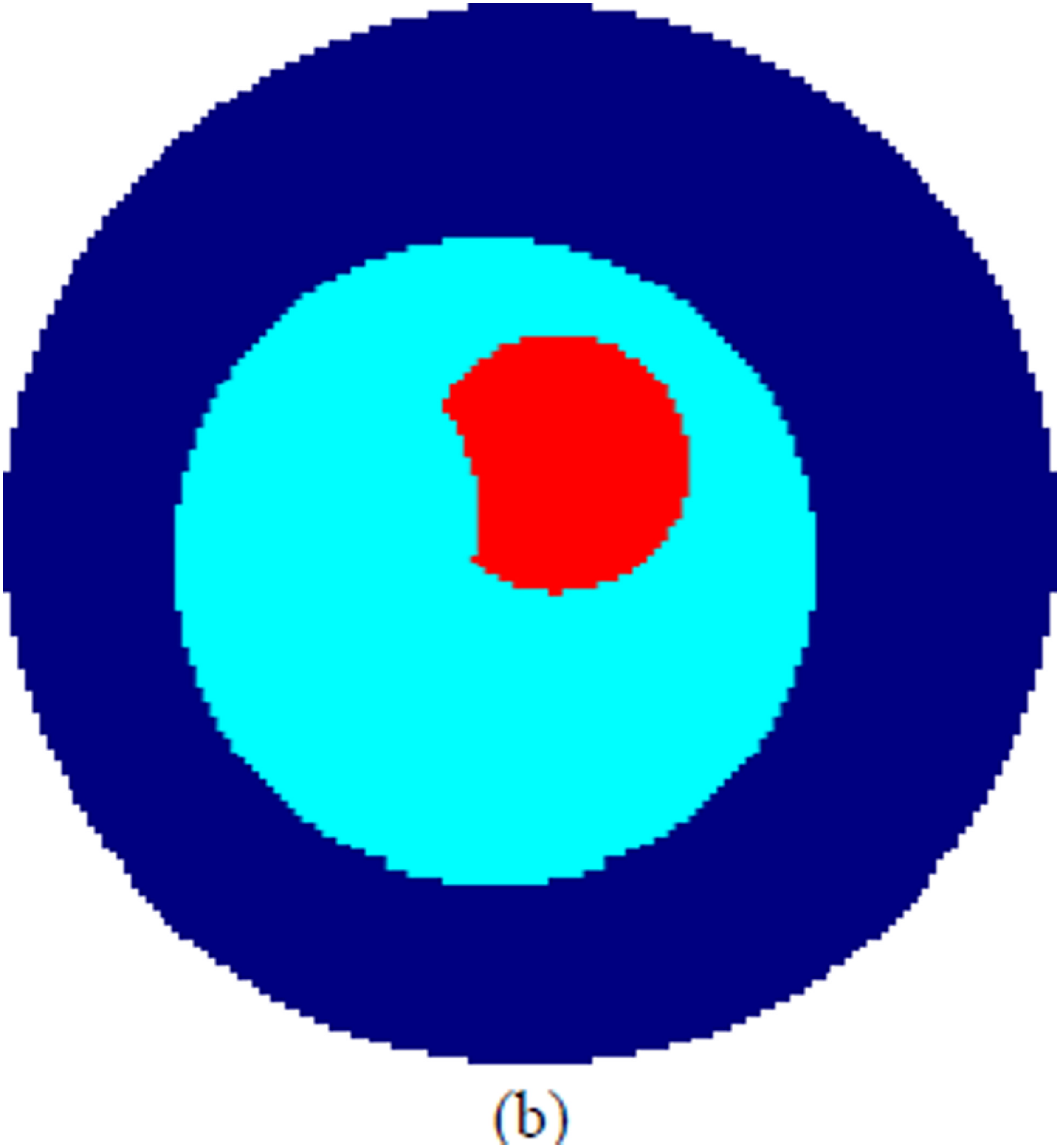


Fig. 4.
(a) MRI Image corresponding to the same plane where microwave data was collected, (b) 2D mask

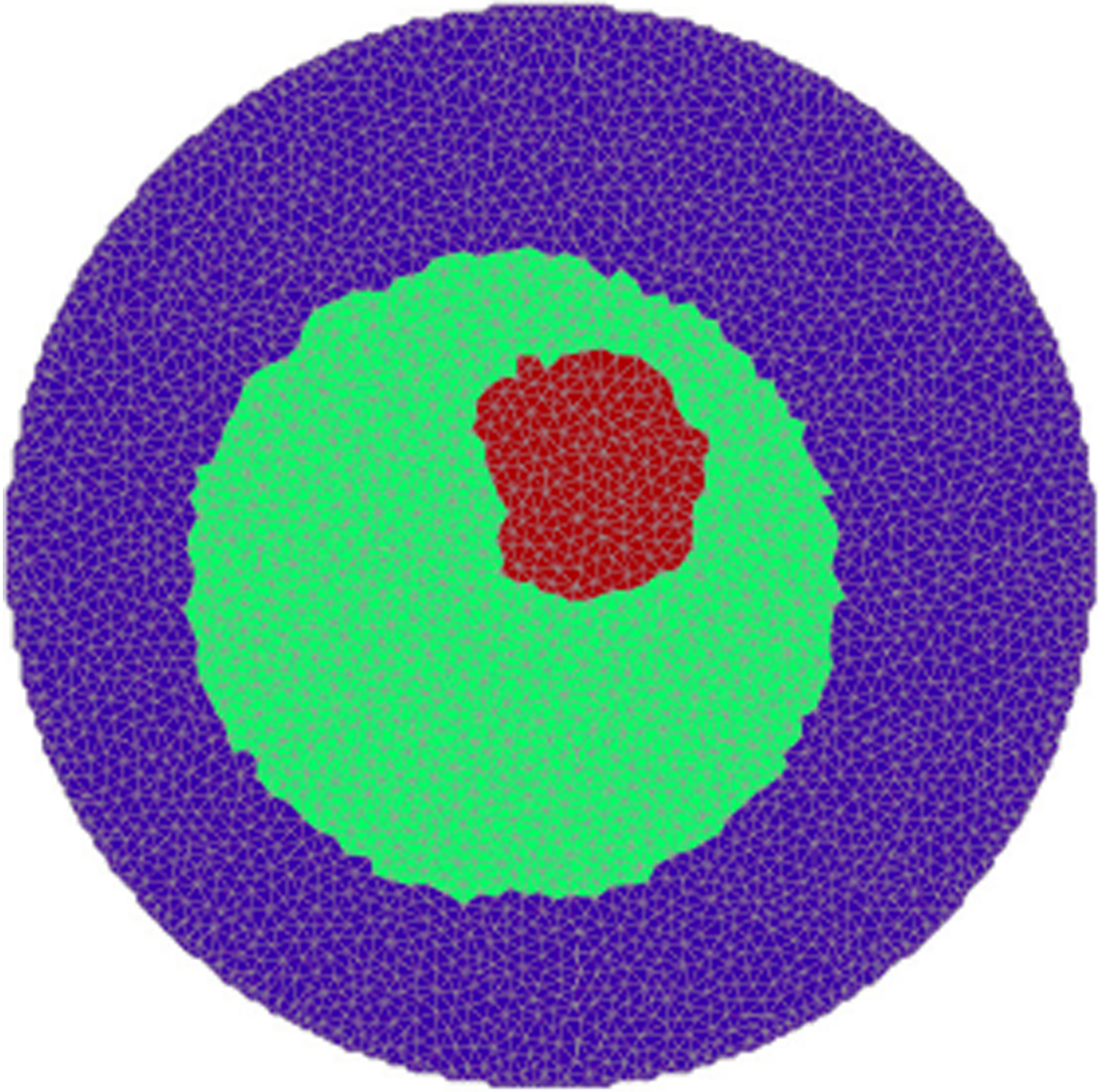
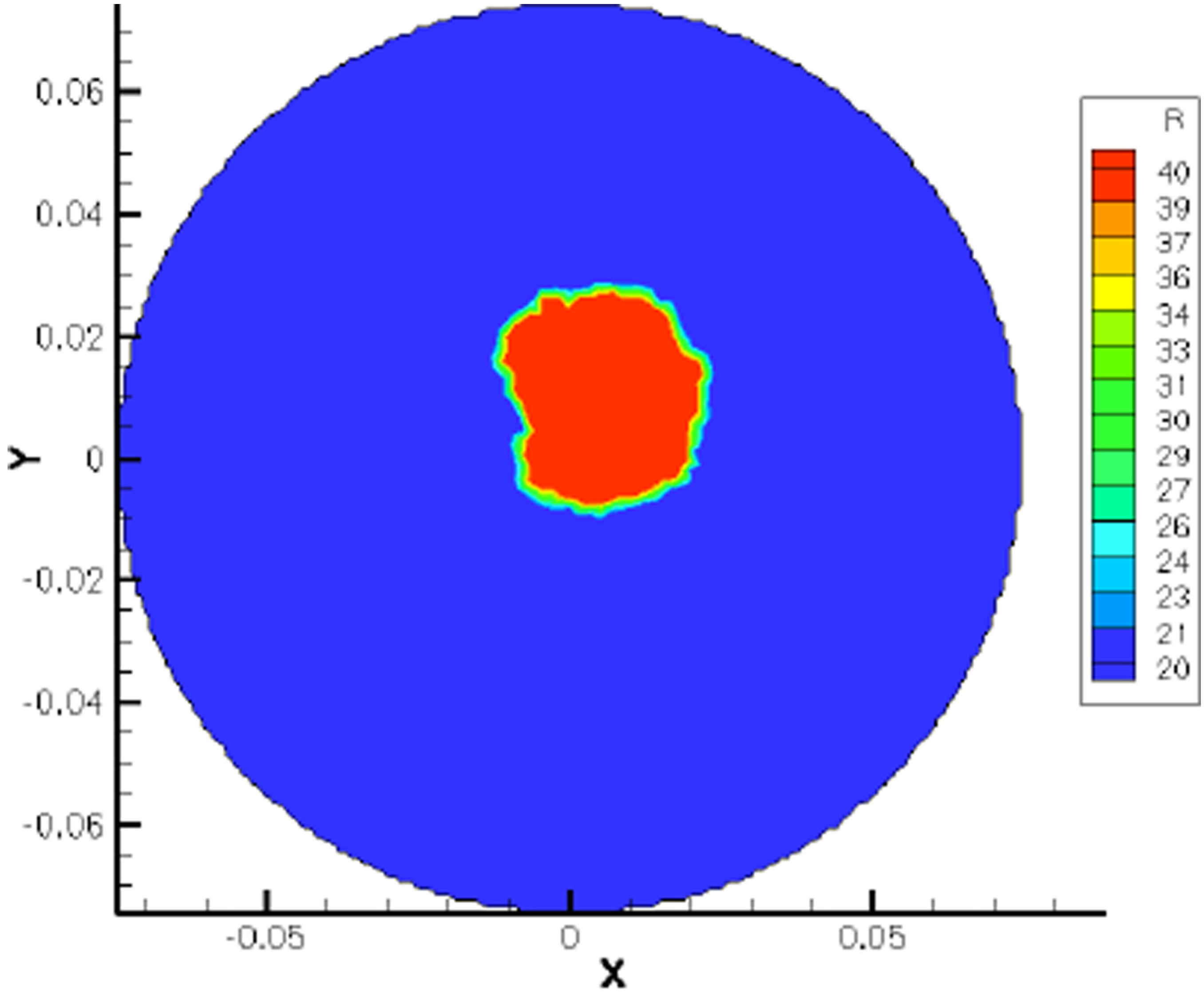


Fig. 5.
2D parameter reconstruction mesh used for the soft-prior regularization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0.04
0.02
Y
0
-0.02
-0.04
-0.06
-0.05
0
0.05
X
R
40
39
37
36
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20

(a)

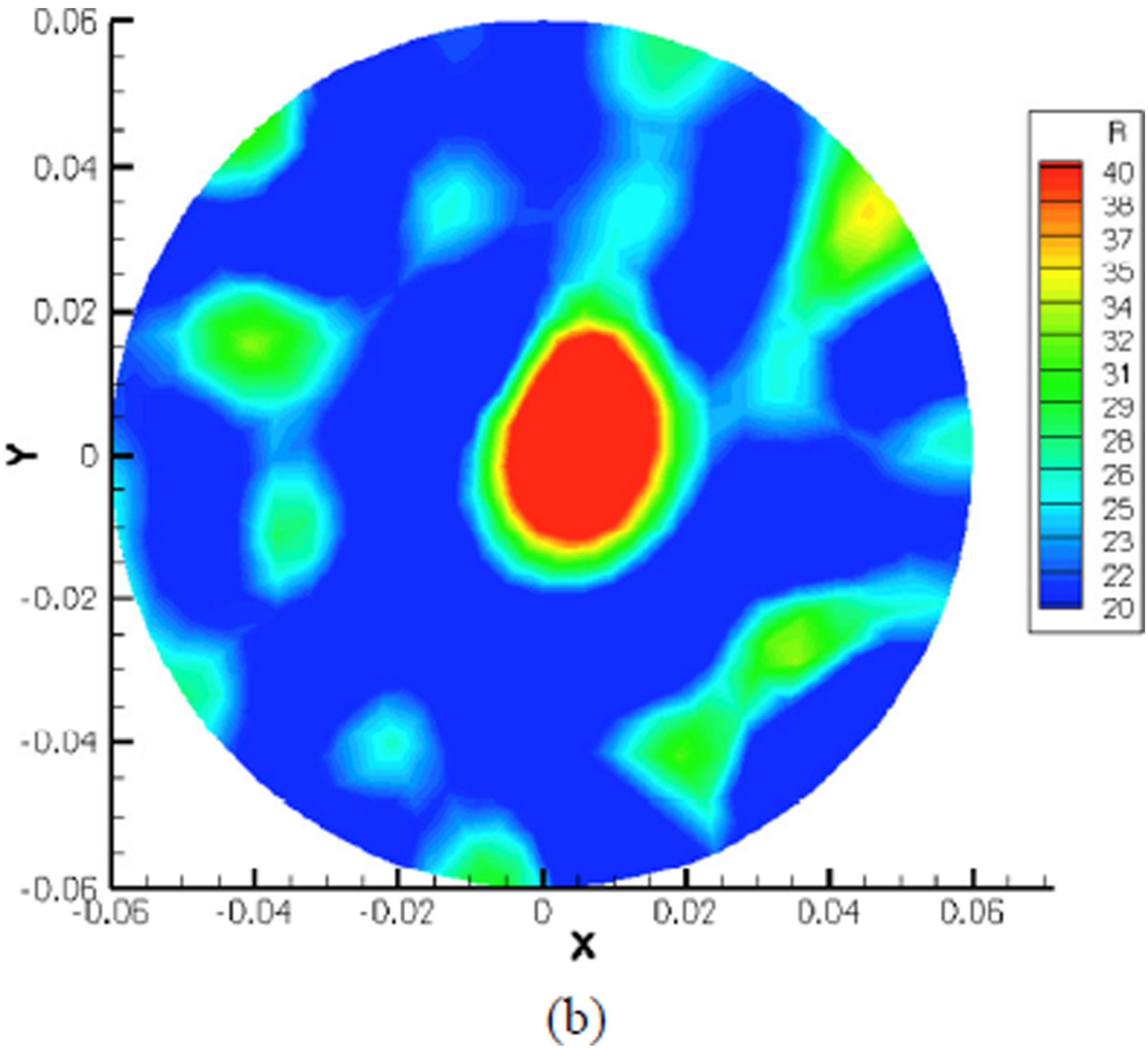

Fig. 6.
1300 MHz reconstructed permittivity images (a) with and (b) without prior spatial information.