Artificial Tactile Sensing Capability Analysis in Abnormal Mass Detection with Application in Clinical Breast Examination

A. Mojra, S. Najarian, S.M. Towliat Kashani, F. Panahi

***Abstract*—A new method based on the real breast tissue structure is proposed to investigate effects of major anatomical features and geometrical parameters involved in the clinical breast examination (CBE) performed either by a breast surgeon or methods based on new non-invasive artificial tactile sensing technology. Indications of abnormal mass existence in different models are elicited from the computational analysis. Simulation results are then compared with the physician feelings from his sense of touch which are in complete agreement. Artificial tactile sensing results can be directly applied to CBE in order to reduce misjudgments in the diagnosis procedure.**

***Index Terms*—Artificial tactile sensing, Breast lesions, Computational finite element analysis, Biomimic**

I. INTRODUCTION

Soft tissue abnormalities are often correlated to a local change in mechanical properties [1]. For instance, physicians use palpation widely as a qualitative diagnostic tool for breast lesions [2]. However, anatomical and physiological variations of healthy and unhealthy breast tissue among individuals and even in different quadrants of one's tissue cause enormous complexities during tissue examinations and diagnosis procedure. This fact is so important that the final diagnosis of each patient is highly dependent on the skillfulness of the physician. Nowadays physicians try to improve their diagnostic abilities by performing more reliable methods on the patients.

The major modalities used in hospitals today are ultrasound, mammography, magnetic resonance imaging (MRI) and biopsy.

Ultrasound is the sound waves propagated in the tissue with frequency greater than 20 kHz. It is a useful technique for evaluating the suspicious lesions in the breast. The minimum tumor size detectable by ultrasound imaging is around 10 mm [3].

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Mammography is a specific type of imaging technique which uses low-dose x-rays to take the x-ray image of the breast. Mammogram is one of the gold standards used in early detection of breast cancer. The smallest tumor size detectable by mammography is around 10 mm [4].

Magnetic resonance imaging (MRI) produces high quality images of inside of the human body [5]. In detecting and screening breast cancer, breast MRI becoming an important tool nowadays. The high contrast and high-resolution of breast MRI images cannot be obtained by other techniques. But breast MRI is a long and costly technique, and it is difficult to differentiate between benign and cancerous lesions [6]. Patients with benign breast disease may have indications on the MRI that malignant breast diseases have.

However, all these imaging techniques are considered to be invasive for the sake of using waves, radiations or magnetic fields that can be harmful for the body. Moreover, these techniques are usually not applicable for young patients with dense breasts. In a fatty breast also they do not have any benefit either. Fatty or dense breasts may cause the masking of lesions especially when they are small in size [5].

The artificial tactile sensing is a new non-invasive method for obtaining properties of a mass confined in the soft tissue [7]–[10]. Two and three-dimensional models are usually used to simulate the mass and biological tissues, and the characteristics of the mass are obtained from graphs and diagrams of stress distribution on the surface of the tissue [11], [12].

In the present study, using a phantom of the real breast model instead of the simplified models used in previous studies, we improved the nodule detection capability. Effects of fatty breasts or dense tissue regions which are the major problems of breast surgeons in CBE or even imaging modalities are simulated computationally and investigated thoroughly. Here, we employed a tactile approach and considered effects of dense regions, fat layer thickness and lesion depth variations involved in this problem. The results of this investigation can be directly applied to the incorporation of tactile sensing in artificial palpation.

II. MATERIALS AND METHODS

Based on breast anatomy a phantom of a real breast tissue is developed with geometrical parameters listed in Table 1. This phantom consists of three major layers which are gland, fat and skin and is developed.

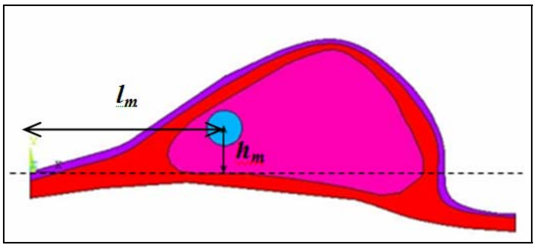

Fig. 1: a simplified model of the breast with consideration of three mentioned layers developed with the ANSYS software (Release 10) (Right). [13]

Table 1: Geometrical parameters of the breast tissue model. [13]

breast	width *(w)* (x-dir)	230 mm
	height *(h)* (y-dir)	70 mm
	fat thickness *(t_m)*	5-10 mm

Mechanical behaviors of the breast tissue model are summarized in Table 2. In order to study the capability of artificial tactile sensing in nodule detection, an abnormal mass is embedded in the breast tissue. The mass is assumed to be Phyllodes tumor which is typically a kind of a malignant mass. The mass radius is assumed to be 10 mm.

Table 2: Geometrical parameters of the breast tissue model. [14]

	Elastic Modulus(kPa)	Poisson's ratio
Skin	12	0.49
Fat	4.8	0.49
Gland	19.2	0.49
Tumor	57.6	0.3

Definition of the problem: Each breast tissue is divided into four quadrants which are upper-outer quadrant (UOQ), upper-inner quadrant (UIQ), lower-outer quadrant (LOQ) and lower-inner quadrant (LIQ). Moreover, two major regions are defined on each breast which are medial and lateral ones. The medial region is the part which consists of UIQ and LIQ while the lateral region includes UOQ and LOQ. Lateral region anatomically has the most volume of tissue in comparison with medial part. Ribs are more sensible under the medial part. In a CBE a physician may have a misdiagnosis just because of this natural anatomical feature. Medial regions are naturally felt to be stiffer than the lateral regions even in the absence of any abnormal mass. Moreover, increase of tissue density in the lateral parts may cause the lesion to be faded out in the surrounding tissue. In this study we would consider tumor position in both medial (Med) and lateral (Lat) parts and the distance from the areolar margin (Arl) and investigate the mass coordinate's effect on the capability of nodule detection. Table 3 exhibits exact coordinate of different lesions considered in our simulation.

Table 3: Tumor geometrical coordinates of the breast tissue models

Mass number	1 (Med)	2 (Med-Arl)	3 (Arl-Lat)	4 (Lat)
l_m(mm)	110	150	190	217
h_m(mm)	35	56	51	14

Thickness of the fat layer *(t)* is a determinant factor of fatty breasts and is one of the most effective parameters influence the accuracy of the CBE and all imaging techniques. In the present study we would thoroughly investigate effects of fatty breasts on the capability of nodule detection. Table 4 displays fat layer thickness which is in fact the difference between the fat thickness of the reference model and the new models.

Table 4: Fat layer thickness variations

t-t_m (mm)	5	10	15	20	30

Rather than the anatomical position of the lesion (medial or lateral), depth of the mass plays a very important role in the ability of all detecting techniques. In this survey, we modeled one superficial mass and one deeply located one and compare the great difference appears on the surface of the tissue. Coordinates is shown in Table 5.

Table 5: Tumor geometrical coordinates of the breast tissue models

Mass depth	Superficial	Deep
l_m(mm)	110	110
h_m(mm)	35	10

Finite element modeling and boundary conditions: This problem was modeled and solved by the numerical method of finite element analysis, using ANSYS software (Release 10.0). The common surface between tissue and tumor was glued together in order to keep continuous strain in consequence of deformation. The model was meshed with SOLID 42, which shows quadratic displacement behavior and is well suited for modeling irregular meshes. For the boundary condition, Pectoralis muscle located in the base of breast tissue restricts the movement of the model in the vertical direction. So, the base line of the model is fixed. By doing this, it is possible to avoid rigid body motion and solve the problem statically. However, upper surface of the model undergoes uniform and vertical 5mm compression.

III. RESULTS

According to the anatomical feature variations in Table 3, a number of cases were modeled and solved by the software and two specific results were extracted from the simulations which are as follows:

1. The stress distribution in the tissue, called the tactile image.
2. The stress graph, which is taken on the path defined on the upper surface of the model, called the tactile graph.

The following results can be elicited from tactile images and tactile graphs:

- Appearance of the effects of an embedded object on the surface in tactile images; the appearance of the symptoms of the tumor on the surface of the tissue is the most fundamental result that confirms the accuracy and reliability of the artificial tactile method.
- Appearance of an overshoot in stress graphs; in stress graphs that are taken along the defined path, there is an increase (overshoot) in the amount of stress that demonstrates the tumor existence.

It can be evidently elicited from Figure 2 that the overshoot related to the tumor existence has a marked increase as we move toward the medial parts. Moreover, rather than the tumor peak, the tactile graphs reach to other maximum in the vicinity of the areolar margin of

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the nipple which is mainly due to the most accumulation of the glandular stiff tissue at this region. However, this tissue peak may even fades out the tumor peak in the lateral parts and causes false diagnosis in nodule detection.

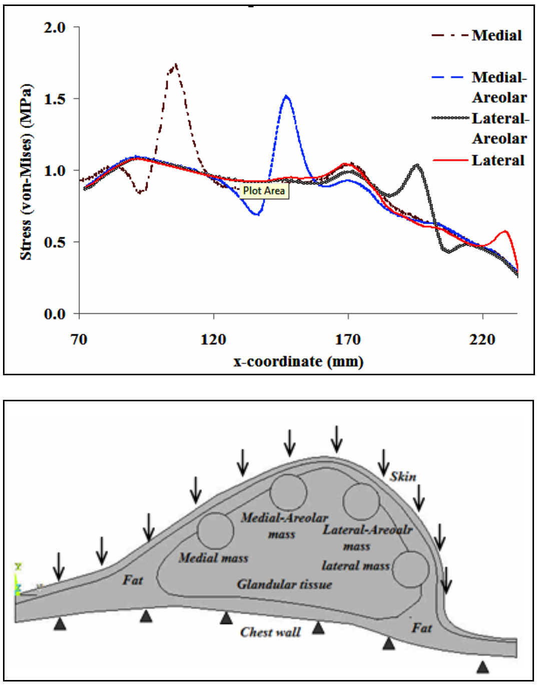

Fig. 2: Stress graphs for different values of tumor anatomical position from the areolar margin from Table 2 (Up); Computational model of different breast lesions displayed together (Down)

The tactile image of the lateral mass is plotted in Figure 3. It can be clearly seen that the surrounding tissue weakens effect of the embedded object on the surface of touch.

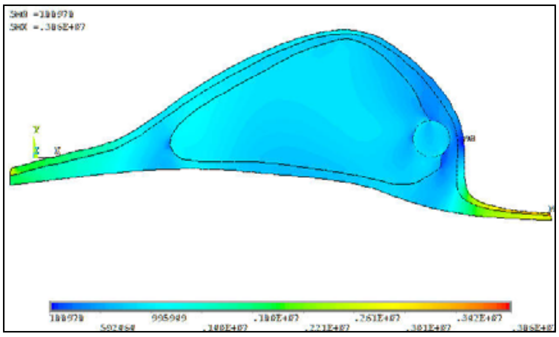

Fig. 3 Tactile image for the lateral tumor from Table 2.

Maximum equivalent stress is calculated for seven masses randomly distributed superficially in the breast tissue. (Figure 4) Location of the lesions in accordance to the areolar margin is symbolized by "Med" stands for the medial, "Med-Arl" for the mass between areolar margin and closer to the medial section, "Arl-Med" for the mass between medial section and closer to the arolar margin and the same for the lateral lesions.

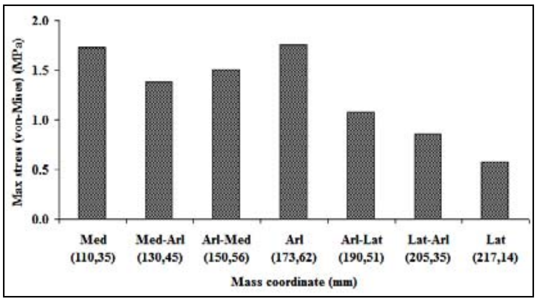

Fig. 4: Maximum equivalent stress for seven masses randomly distributed superficially in the breast tissue.

Figure 4 illustrates that for lesions located in the medial parts, marked increase of the maximum stress is a clear symptom the embedded object whereas it is not the same evident for the lateral objects.

Effect of fatty breast is displayed for different fat layer's thickness in Figure 5. Noticeable increase for a normal breast in comparison with a fatty breast in which fat layer thickness is almost tripled is evident. Even for thicker fat layers mass effect disappears on the surface of the tissue and makes it almost impossible to be detected by a simple palpation of the physician. It also makes it difficult for other imaging techniques to be discovered clearly.

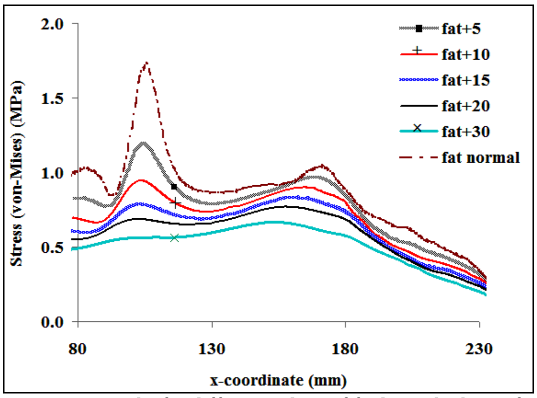

Fig. 5: Stress graphs for different values of fat layer thickness from Table 3.

A comparison between the maximum stresses experienced by a "no-mass" situation with models of different fat thickness is proposed in Table 6. Data comparison illustrates that for fatty breasts with fat thickness almost 1.5 times more than the normal tissue, maximum stress sensed on the surface is even less than a normal breast which doesn't include any mass. This point would clarify why a surgeon is not able to detect small and even medium-sized masses in a large fatty breast.

Table 6: Maximum stress experienced by different models with various fat layers' thickness.

t-t_m (mm)	0	5	10	15	20	30
S_{max} (von-Mises) (MPa)	1.73	1.20	.94	.83	.77	.67
Ratio ($S_{mass}/S_{no\ mass}$)	1.65	1.15	.90	.80	.74	.64

Mis-diagnosis can be also achieved for deeply located tumors. Figure 6 displays stress contours for two superficial and deeply located lesions. It can be elicited from the figure that there is a sharp stress variation on the tissue surface when we are dealing with a superficial tumor, which makes it much discoverable by the palpation. Smoother changes for a deeper mass are apparent in Figure 6 (Down). Moreover, the tumor peak is already at higher levels for a superficial mass as we already expected before.

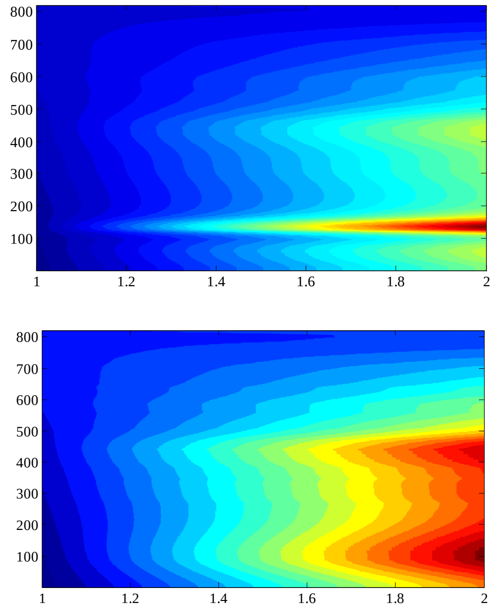

Fig. 6: Stress contours for different depth values from Table 5.

IV. DISCUSSIONS AND CONCLUSIONS

For the sake of mimicking palpation of a breast surgeon in the clinical breast examination (CBE), we have chosen an artificial tactile sensing approach which is a non-invasive method provides more accurate documentation of the examined tissue. A real model of breast tissue was provided computationally and effect of anatomical features and geometrical parameters was thoroughly considered. These parameters include fat layer thickness as a criterion for a fatty breast, anatomical position of the embedded object and depth estimation of the tumor. Results include tactile image and tactile graph which appear inside and on the surface of the tissue respectively. Having modeled all parameters variations and solved all models, the results show that artificial tactile sensing is highly capable of predicting nodule existence with accurate documentation of what is normally sensed by human sense of touch. It can also be elicited from computational results that fatty or dense breasts may cause the masking of lesions especially when they are small in size. Exact documentation of the palpation of the tissue may be helpful in characterizing mass even in a fatty or dense breast. Depth of a mass also plays a very important role in the capability of mass detection. That is the main reason for late detection of deeply located mass which may be detected only when they are much enlarged. Artificial tactile sensing is a new developing technique with the goal of being non-harmful and improves early detection of disease diagnosis.

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