Young's Modulus Distribution Prediction Analysis of Elasticity Imaging Technique Based on Location of Tumors

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Abstract
Soft tissue Elastography is a well-established technique that has received substantial attention in recent years in the detection and classification of tumors. The core target of elastography in the field of breast imaging is to identify the tumor at its early stage, providing a non-invasive method for obtaining the mechanical properties of tissue in the breast. Theoretically, elastography data can be utilized to obtain the Young's Modulus distribution of the targeted soft tissue region. However, elastography techniques are only able to extract the distribution of strain in the selected area. The strain data can be calculated from ultrasound based imaging techniques. To obtain the actual Young's modulus requires the knowledge of stress distribution around that region, which is challenging in different aspects. A number of research groups are working on prediction of stress distribution of tissue. In this paper, we investigate the error between the simulated results to the actual value of stress distribution, from differing external sides of the tissue, as well as based on the location of the tumor. This error, based on the location, presents the order of challenges that must be overcome in order to predict the stress distribution. .

Key words:
Breast model, finite element, COMSOL Multiphysics, elasticity imaging, 2-dimensional model, error analysis.

1. Introduction

Elasticity imaging is a technique which provides information about the mechanical properties (e.g.,elasticity or elastic modulus, such as Young's modulus) of tissue. It utilises this information to distinguish between normal soft tissue and cancerous hard tissue. This makes it useful in the detection of Breast cancer at an early stage. The death rate of breast cancer is very high amongst women. It is the second-leading cause of cancer deaths among women in the United States [1]. Almost one-third of the patients affected with breast cancer could survive if their cancer is detected at an early stage and treatment is provided in accordance. Worldwide, nearly 400,000 lives could be saved a year as a result of early detection of cancer [2].

Available breast cancer detection techniques like clinical breast examination (CBE) or X-ray mammography have low sensitivity compared to Breast magnetic resonance imaging (MRI) [3]. However, MRI is costly and does not provide much specificity for breast cancer diagnosis [3] Dynamic contrast-enhanced MRI (DCE-MRI) technique provides acceptable sensitivity as well as specificity for differentiating between benign and malignant lesions [4]. Nevertheless, DCE-MRI is not only costly but also requires exogenous contrast agents to be injected to have such contrast. Elasticity imaging is a technique for breast cancer detection which employs tissue stiffness as a contrast mechanism. The technique is established on the fact that the pathological state of the breast cancer highly correlates with their mechanical properties, such as Young's modulus (or shear modulus) and viscoelasticity [5].

Conventional elasticity imaging displays strain images. Elastography which uses quasi-static compression [6] is considered to be the most established approach. It estimates the strain within the tissue, which can be interpreted to measure the Young's modulus distribution indirectly, as the Young's Modulus is a relationship between the stress applied and the strain resulting. Here assumption of a constant stress field within the tissues is made. However, the stress within the tissues decays with depth and concentrates at the boundaries of inclusions [6]. Due to the non-uniform stress distribution within the tissue, several mechanical artifacts could exist in the axial strain image and may compromise the diagnosis in the clinic [8]. To overcome this limitation, many researchers are devoted to reconstructing the Young's or shear modulus within the tissue by using certain constraints and the estimated displacements or strains [9-11].

Many investigations have been performed using motion of the ultrasound probe as thesource of quasistatic mechanical excitation [14]. Tissue compresses when the probe is pushed firmly against the surface, and relaxes when the probe is held lightly. If motion of the ultrasound probe causes a uniform change in the axial component of

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longitudinal stress, then strain at each point in the image is inversely proportional to Young's modulus, if the behavior is isotropic linear-elastic. M. K. Metwally et al. [15] done some work to show the influence of the anisotropic mechanical properties of the breast cancer on Photoacoustic Imaging (PI). Is a completely simulation based work which shown the impact of the anisotropic behavior of the tumor.
In this work, error is calculated between theoretical and estimated Young's moduli found from simulation, based on location of tumor. We investigate the influence of position of the tumor to estimate the modulus and which provides an effective guideline to make the modulus reconstruction system more robust.

2. Method

2.1 The Tissue Model

A model of breast tissue is created using COMSOL Multiphysics software. COMSOL Multiphysics is a cross-platform finite element analysis, solver and multi-physics simulation software [3]. It allows for the creation of a conventional physics-based user interface. The size of the overall model is taken as 3 cm with and 3.6 cm depth. The tumor is modeled by 1 cm diameter circular structure and placed in different positions for analysis. Skin and fat tissue depth is taken as 0.1 cm and 0.5 cm respectively where the width is 3 cm.

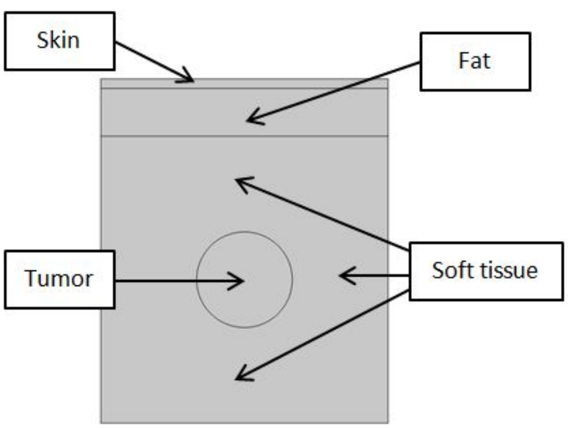


Fig. 1 Geometry of the FE model of breast tissue

Water is the selected material used to represent various parts of the model. Distinctions were made between soft tissue, tumor, skin and fat by varying the mechanical properties. The altered properties included the Poisson's ratio and Young's modulus according to the literature [14]. Poisson's ratio is the ratio of the proportional decrease in a lateral measurement to the proportional increase in length in a sample of material that is elastically stretched. Young's modulus is a measure of the ability of a material to withstand changes in length when under lengthwise tension or compression. Sometimes referred to as the modulus of elasticity, Young's modulus is equal to the longitudinal stress divided by the strain. Poisson's ratio is taken as 0.495 for soft tissue, tumor, skin and fat. Young's modulus is considered as 10 kPa, 40 kPa, 200 kPa and 1.5 kPa for soft tissue, tumor, skin and fat respectively. It is assumed that bone is at that side. All the other sides were left free for movement.

Table 1: Mechanical properties of tissue components of breast

Tissue type	Poisson's ratio	Young's modulus
Soft tissue	0.495	10 kPa
Tumor	0.495	40 kPa
Skin	0.495	200 kPa
Fat	0.495	1.5 kPa

2.2 Variation Of Tumor Position

The tumor is placed in three different location inside the soft tissue. Naturally the tumor can be very close to the skin or it can be little bit far or even far away from the skin. We modelled our simulation based on those natural position of the tumor. Considering the lower left corner as the center (0,0) of the model, the tumor's center is placed at Position-01 (1.5,2.0), Position-02 (1.5,1.5) and Position-03 (1.5,1.0). The tumor position is changed vertically but not horizontally. For horizontal change of tumor position, the effect of skin at upper side and the effect of bone at lower side is the same. Therefore, vertical changes have been made to calculate the error closer to skin and closer to the bone.

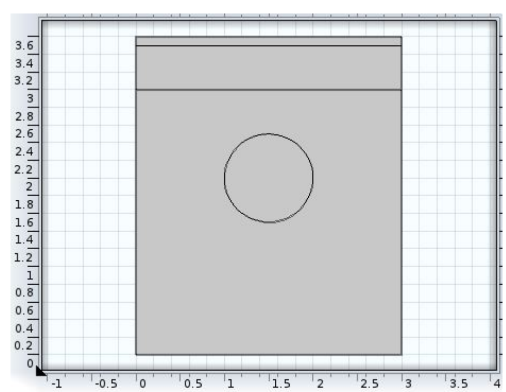


Fig. 2 Tumor at top side of the soft tissue (Position-01)

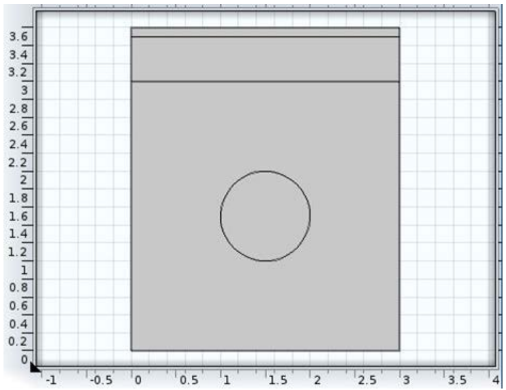


Fig. 3 Tumor at middle of soft tissue (Position-02)

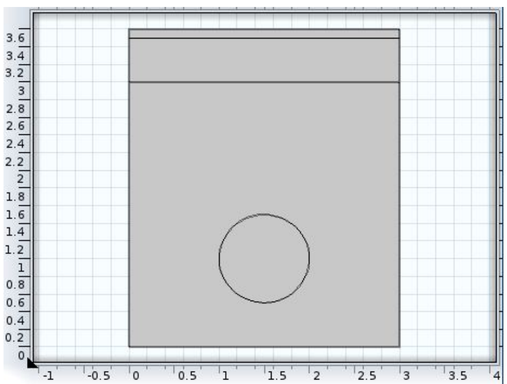


Fig. 4 Tumor at bottom side of the soft tissue (Position-03)

2.3 Young's Modulus Reconstruction

For Young's Modulus reconstruction, stress and strain values are required. In a practical scenario, compression is made by the ultrasound probe. The stress field is usually non-uniform, so strain data are ambiguous, but strain imaging is the simplest way of displaying quasistatic deformation data to provide a visual indication of variation in mechanical properties [7, 15].

In our model we utilizes a fixed displacement of 0.03 cm to represent the compression from an ultrasound probe. Stress and strain values are then found directly from the simulation. Both the stress and strain value points are depends on the mesh pattern of the model. Here we have 108,661 data point. In the multiphysics software the data points are in random position. This data set is channelized to MATLAB for future calculation. Young's Modulus is calculated based on those data set.

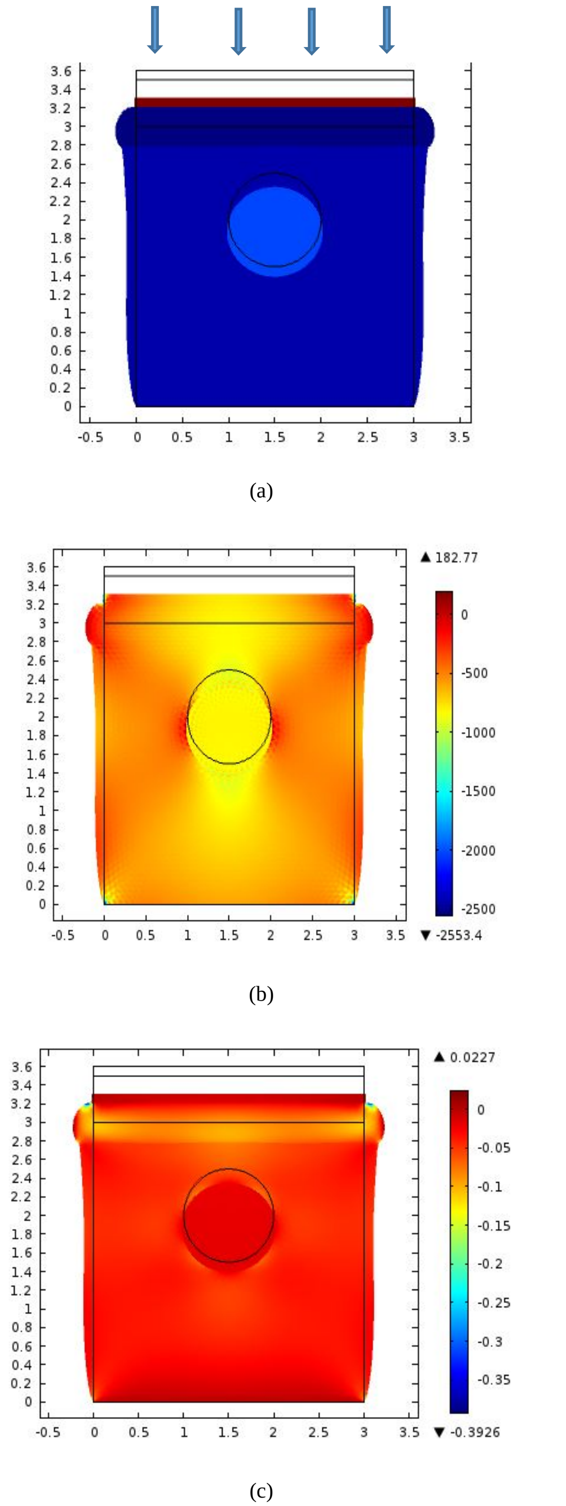


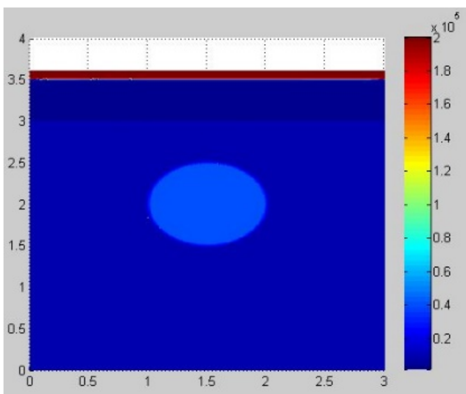
Fig. 5 Ultrasound probe is pressed at the top surface which is represented by fixed displacement of 0.03 cm; (a) Fixed displacement field is applied at the top surface, (b) Stress distribution found from Comsol Multiphysics, (c) Strain distribution found from Comsol Multiphysics

In our analysis an average value of stress is calculated by the obtained stress data. This average value of stress is assumed as constant for all the portions of the model. This average stress value, alongside respective absolute values of strain at each point of the model, is then considered to calculate the Young's modulus. It defines as the Calculated Young's Modulus value, which varies from the Actual Young's Modulus value. Actual Young's Modulus data also exported to excel database and hence to MATLAB.

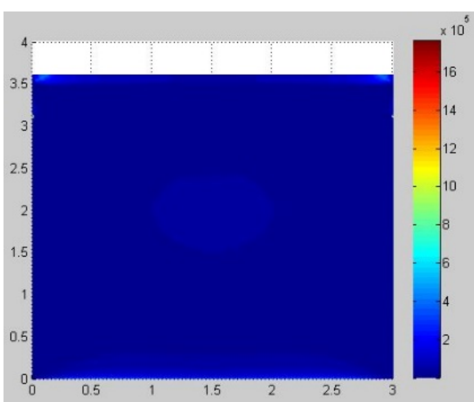
$$Average\ stress = \frac{\sum_i^n \sum_j^m |stress_{ij}|}{n*m} \quad (1)$$

$$Calculated\ Young's\ Modulus = \frac{Average\ stress}{|strain_{ij}|} \quad (2)$$

Where i and j are the row and column position of the grid respectively. n (n = 361) and m (m = 301) are the number of row and column of the grid respectively.



(a)



(b)

Fig. 6 (a) Actual Young's Modulus distribution found from MATLAB, (b) Calculated Young's Modulus distribution found from MATLAB

2.4 Error Estimation

The percentage of error between the Actual Young's Modulus and the Calculated Young's Modulus are calculated for different position of the tumor. Deviation or error from actual result is calculated both inside and outside the tumor. The error inside the tumor is calculated for the position marked with the red box in the figure. The error outside the tumor is calculated for seven positions: Upper side, Lower side, Left side, Right side, Diagonal-1, Diagonal-2 for all the different position of the tumor.

$$Percentage\ of\ error = \frac{|(\text{Actual Young's Modulus}) - (\text{Calculated Young's Modulus})|}{(\text{Actual Young's Modulus})} \times 100\% \quad (3)$$

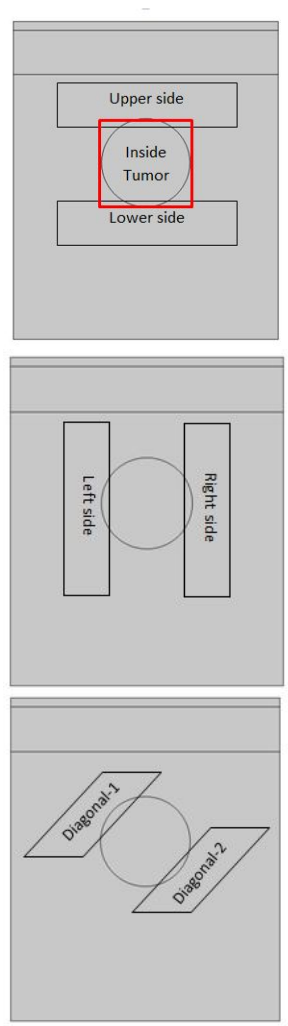


Fig. 7 Various positions for error calculation.

The error was calculated for all seven positions using the proposed model of Position-01. After that the position of the tumor is changed vertically (Position-02) and the error calculation was repeated for all seven positions. The whole process is similarly repeated for Position-03.

3. Results and Discussion

Table 2 shows the percentage error values for all the positions we considered. The values have been plotted and shown in Figure 8. From the graph we find that the error inside the tumor is almost the same and very small for all three positions. In the case of error outside the tumor, for all positions, the error increases with depth, except in the case of Diagonal-1. For Diagonal-1, the error is greater at Position-01, which is closer to the skin. Then error decreases at Position-02, and again increases slightly at Position-03. It can be also observed that the deviation is very high for the lower side of the tumor when we consider the tumor is far from skin. In case of upper side the error deviation is very negligible. For right side and left side the error are the same and they are supper imposed in the diagram.

Table 2: Percentage of error for various positions (Applied displacement 0.3 cm)

	Inside Tumor	Upper side	Lower side	Right side	Left side	Diag 1	Diag 2
P-01	14.3	25.0	49.8	41.5	41.5	48	37
P-02	13.3	35.6	79.5	58.5	58.5	18.95	43.8
P-03	15.6	39.1	188	83.2	83.2	27.96	74.4

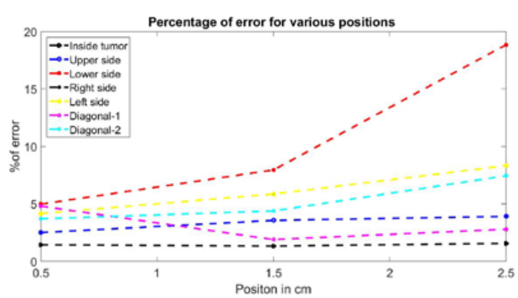


Fig. 8 Percentage error for various positions

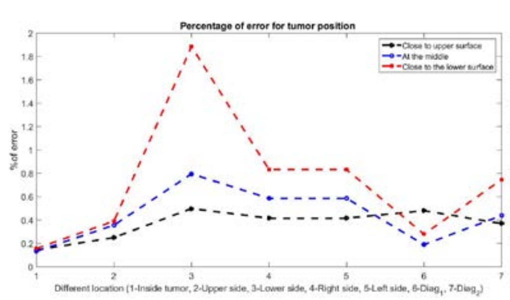


Fig. 9 Percentage of error for different orientation

This study aimed at investigation the influence of the position of the tumor, with respect to the skin, on the modulus reconstruction. The investigation is done by using the COMSOL Multiphysic and MATLAB software. Here the COMSOLE Multiphysic helps to understand the model and to get the strain and stress value of all the points of the model. MATLAB gives the freedom to do the calculation. The simulation result demonstrate that modulus reconstruction may not face any challenge inside the tumor itself. On the other hand the prediction algorithm will face challenges to predict the modulus for the lower location of the tumor when that is far away from the skin and it will gradually increase the prediction error. For a single symmetric tumor the error rate on both left and right side will behave same but for multi tumor case it might be different.

4. Conclusions

The error calculation method we used in this paper takes into account realistic boundary conditions and the non-uniform distribution of stress, leading to a reliable Young's Modulus reconstruction. This work can help to improve the modulus reconstruction technique hence the elasticity imaging technique by providing useful information about noise induction for different location of tumors. This will lead to contribute to the improving the accuracy of detection of breast cancer through elasticity imaging, which is still in a developmental state. Conventional elasticity imaging shows strain images, and can provide improved ability to determine the lesions' location and shape when compared to the corresponding B-mode imaging, which is more commonly used for breast cancer detection. Although current approaches impose assumptions about the response of tissues to mechanical stimuli and are forced to create images with limited sensory information from the imaging device, they nevertheless provide unique diagnostic information about structure and function. Similar work can be done for multi number of tumor for different location and with the combination.

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References

[1] R. Siegel, D. Naishadham and A. Jemal, "Cancer statistics, 2013", CA: A Cancer Journal for Clinicians, vol. 63, no. 1, pp. 11-30, 2013.
[2] Worldwide Breast Cancer. http://www.worldwidebreastcancer.com, Accessed on: Jan. 25, 2017.
[3] J. E. Joy, E. E. Penhoet, and D. B. Petitti, Institute of Medicine (US) and National Research Council (US) Committee on New Approaches to Early Detection and Diagnosis of Breast Cancer, Saving Women's Lives: Strategies for Improving Breast Cancer Detection and Diagnosis. Washington, DC, USA: Nat. Acad. Press, 2005.
[4] S. C. Rankin, "MRI of the breast," Brit. J. Radiol., vol. 73, no. 872, pp. 806–818, Aug. 2000.
[5] S. Goenezen, J. Dord, Z. Sink, P. Barbone, J. Jiang, T. Hall and A. Oberai, "Linear and Nonlinear Elastic Modulus Imaging: An Application to Breast Cancer Diagnosis", IEEE Transactions on Medical Imaging, vol. 31, no. 8, pp. 1628-1637, 2012.
[6] L. Sannachi et al., "Non-invasive evaluation of breast cancer response to chemotherapy using quantitative ultrasonic backscatter parameters," Med. Image Anal., vol. 20, no. 1, pp. 224–236, 2015
[7] J. Ophir, I. Cespedes, H. Ponnekanti, Y. Yazdi, and X. Li, "Elastography: a quantitative method for imaging the elasticity of biological tissues,"Ultrasonic imaging, vol. 13, pp. 111-134, 1991.
[8] F. Kallel and M. Bertrand, "Tissue elasticity reconstruction using linear perturbation method", IEEE Transactions on Medical Imaging, vol. 15, no. 3, pp. 299-313, 1996.
[9] F. Kallel and M. Bertrand, "Tissue elasticity reconstruction using linear perturbation method", IEEE Transactions on Medical Imaging, vol. 15, no. 3, pp. 299-313, 1996.
[10] M. Doyley, S. Srinivasan, S. Pendergrass, Z. Wu and J. Ophir, "Comparative evaluation of strain-based and model-based modulus elastography", Ultrasound in Medicine & Biology, vol. 31, no. 6, pp. 787-802, 2005.
[11] A. Oberai, N. Gokhale, M. Doyley and J. Bamber, "Evaluation of the adjoint equation based algorithm for elasticity imaging", Physics in Medicine and Biology, vol. 49, no. 13, pp. 2955-2974, 2004.
[12] J. Ophir, S. Alam, B. Garra, F. Kallel, E. Konofagou, T. Krouskop and T. Varghese, "Elastography: Ultrasonic estimation and imaging of the elastic properties of tissues", Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine, vol. 213, no. 3, pp. 203-233, 1999.
[13] M. K. Metwally, S.H. EI-Gohary, S. M. Ran, K. M. Byun, and Tae-Seong Kim "Influence of the Anisotropic Mechanical Properties of the Breast Cancer on Photoacoustic Imaging", 7th Cairo International Biomedical Engineering Conference Cairo, Egypt, pp. 34-38, 2014
[14] Amit Gefena and Benny "Dilmoney,Mechanics of the normal woman's breast",Kiryat Shmona,vol.11,no.13, pp.4-8, 2007.
[15] J. Lindop, G. Treece, A. Gee and R. Prager, "3D elastography using freehand ultrasound", Ultrasound in Medicine & Biology, vol. 32, no. 4, pp. 529-545, 2006.
[16] N. Miyanaga, H. Akaza, M. Yamakawa, T. Oikawa, N. Sekido, S. Hinotsu, K. Kawai, T. Shimazui And T. Shiina, "Tissue elasticity imaging for diagnosis of prostate cancer: A preliminary report", International Journal of Urology, vol. 13, no. 12, pp. 1514-1518, 2006.
[17] S. R. Mousavi, H. Rivaz , A. Sadeghi-Naini, G. J. Czarnota, and A. Samani "Breast Ultrasound Elastography Using Full Inversion-Based Elastic Modulus Reconstruction", IEEE Transactions On Computational Imaging, vol. 3, no. 4, pp. 774-782, 2017.