Measurement 45 (2012) 663–682

Contents lists available at SciVerse ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Studying the resistivity imaging of chicken tissue phantoms with different current patterns in Electrical Impedance Tomography (EIT)

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A R T I C L E I N F O

Article history:
Received 25 February 2011
Received in revised form 2 December 2011
Accepted 7 January 2012
Available online 15 January 2012

Keywords:
Electrical impedance tomography
Chicken tissue paste phantoms
Chicken tissue block phantoms
Fat inhomogeneity
Bone inhomogeneity
Current patterns
Image reconstruction
Resistivity images
EIDORS
Contrast parameters

A B S T R A C T

A current injection pattern in Electrical Impedance Tomography (EIT) has its own current distribution profile within the domain under test. Hence, different current patterns have different sensitivity, spatial resolution and distinguishability. Image reconstruction studies with practical phantoms are essential to assess the performance of EIT systems for their validation, calibration and comparison purposes. Impedance imaging of real tissue phantoms with different current injection methods is also essential for better assessment of the biomedical EIT systems. Chicken tissue paste phantoms and chicken tissue block phantoms are developed and the resistivity image reconstruction is studied with different current injection methods. A 16-electrode array is placed inside the phantom tank and the tank is filled with chicken muscle tissue paste or chicken tissue blocks as the background mediums. Chicken fat tissue, chicken bone, air hole and nylon cylinders are used as the inhomogeneity to obtained different phantom configurations. A low magnitude low frequency constant sinusoidal current is injected at the phantom boundary with opposite and neighboring current patterns and the boundary potentials are measured. Resistivity images are reconstructed from the boundary data using EIDORS and the reconstructed images are analyzed with the contrast parameters calculated from their elemental resistivity profiles. Results show that the resistivity profiles of all the phantom domains are successfully reconstructed with a proper background resistivity and high inhomogeneity resistivity for both the current injection methods. Reconstructed images show that, for all the chicken tissue phantoms, the inhomogeneities are suitably reconstructed with both the current injection protocols though the chicken tissue block phantom and opposite method are found more suitable. It is observed that the boundary potentials of the chicken tissue block phantoms are higher than the chicken tissue paste phantom. SNR of the chicken tissue block phantoms are found comparatively more and hence the chicken tissue block phantom is found more suitable for its lower noise performance. The background noise is found less in opposite method for all the phantom configurations which yields the better resistivity images with high PCR and COC and proper IR_{Mean} and IR_{Max} neighboring method showed higher noise level for both the chicken tissue paste phantoms and chicken tissue block phantoms with all the inhomogeneities. Opposite method is found more suitable for both the chicken tissue phantoms, and also, chicken tissue block phantoms are found more suitable compared to the chicken tissue paste phantom.

1. Introduction

Electrical Impedance Tomography (EIT) [1–4] has been researched extensively in the medical field [5–7] as well as in other areas like industrial process control [8], chemical engineering [9], geotechnical research [10] and

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doi:10.1016/j.measurement.2012.01.002

biotechnology [11] due to its several advantages [12–14] over other computed tomographic techniques [15]. Practical phantoms [2,16–18] with surface electrodes [19–21] are used to assess the performance of EIT systems for their validation, calibration and comparison purposes. In EIT, the impedance images are reconstructed from the surface potentials developed by a constant current signal injected to the boundary ($\partial\Omega$) of the domain (Ω) to be imaged. The sensitivity, spatial resolution and distinguishability of an EIT system depends on the current injection techniques applied for boundary data generation. Different current injection methods called current injection patterns [22] have their own sensitivity to the different inhomogeneity positions in the domain under test.

Studying the impedance image reconstruction with practical phantoms is very essential to assess the performance of an EIT system for its validation, calibration and comparison purposes. Impedance imaging of real tissue phantoms with different current injection methods is also essential for better assessment of the EIT systems. Practical phantoms with saline and solid resistive materials are very popular in EIT as they are low cost, easy to develop and can be developed in any shape. But they cannot be assumed as a perfect mimic of the body parts as the background medium is a purely resistive (saline) whereas none of the human body parts are purely resistive. Hence, real tissue phantoms are essentially required to assess a medical EIT system as it is highly recommended to test, calibrate and evaluate a medical EIT system [7] before applying it on the human subjects for diagnostic imaging. In electrical impedance tomography, current injection patterns have their own current distribution profiles within the domain under test. Therefore, a particular current injection pattern has a definite sensitivity, spatial resolution and distinguishability. In this context, the resistivity images of chicken tissue phantoms with different configurations are reconstructed using different current injection methods. Chicken tissue phantoms with different background medium and different cylindrical inhomogeneities with higher resistivity are developed and the resistivity imaging with different current injection protocols is studied. A 16-electrode array is placed inside the phantom tank filled with chicken tissue paste and chicken tissue blocks as the background medium. A low frequency low magnitude sinusoidal constant current is injected at the phantom boundary with opposite and neighboring current patterns and the boundary potentials are measured. In order to obtain a proper patient safety, a medical EIT system must be designed with a current signal within a safe limit [7]. In the present study all the data are collected by injecting a constant sinusoidal current of 1 mA 50 kHz which can be safely used in a medical EIT [7]. Resistivity images are reconstructed from the boundary data using a standard reconstruction algorithm and the images are analyzed with the resistivity parameters and contrast parameters calculated from the elemental resistivity profile of the images. Boundary data profiles of all the phantom configurations are studied to evaluate the phantom and system performance. Surface potentials of the practical phantoms with homogeneous medium (without inhomogeneity) are also studied to assess the electrode system, background domain homogeneity and the system symmetry and stability.

2. Materials and methods

2.1. Chicken tissue phantoms

Chicken tissue paste phantom and chicken tissue block phantom with different inhomogeneities (diameter, *d*) are developed to obtain the different phantom configurations required to study the resistivity imaging in EIT. The practical phantoms (Fig. 1) are developed with a shallow glass tank (diameter, *D* = 150 mm) and 16 stainless steel electrodes [16] equally spaced on the tank inner wall (Fig. 1a). Geometrically identical 16 rectangular (length: 34 mm, width: 10 mm) electrodes (Fig. 1a) are cut from high quality stainless steel sheet (50 μm thick, type 304) [16] to avoid the localized pitting corrosion leading to the creation of small holes and fixed on tank inner wall (Fig. 1a). All the 16 electrodes are connected with the EIT electronic hardwire through the low resistive flexible multi-strand copper wires and 16 steel crocodile clips (Fig. 1b). All the connecting wires are taken with equal lengths to maintain the identical impedance paths between electrodes and the electronic hardware. The surface electrodes touching the boundary of the background medium or bathing medium [16,17] act as the EIT sensors which interface the phantom with the electronic hardwire for the current injection and voltage measurement.

2.1.1. Chicken tissue paste phantoms

Chicken tissue paste phantoms are developed with chicken tissue paste as the background medium and the chicken fat tissue as the inhomogeneity. Chicken muscle tissue is cut in small pieces and crushed in a mixer grinder to obtain a paste of chicken muscle tissue. The paste is transferred in the phantom tank (Fig. 1c) maintaining a height of the background medium or bathing medium [16,17] in the phantom at 10 mm so that an effective electrode area becomes 10 mm $\times$ 10 mm. The phantom is kept inside a refrigerator for 8 h and a hole (*d* = 35 mm) is made for inserting inhomogeneity. A cylindrical chicken fat tissue (*d* = 35 mm) is inserted into the hole made in the muscle tissue paste carefully (Fig. 1c). A cylindrical stainless steel rod (25 mm dia.) is placed at the phantom center (Fig. 1c) to act as a common mode electrode (CME) [17]. The CME is connected to the ground point of the EIT electronics to reduce the common mode error. The chicken paste conductivity (0.58 S/m) is measured using an impedance analyzer (QuadTech 7600, QuadTech Inc., USA) with a test signal of 1 mA, 50 kHz.

2.1.2. Chicken tissue block phantoms

Electrical impedance spectroscopy [23] of chicken tissues [23] showed that the chicken tissue block exhibit a better impedance response than the tissue paste. In this direction, another chicken tissue phantom is also developed with chicken tissue blocks (Fig. 1d) and cylindrical air hole (Fig. 1e), fat tissue (Fig. 1f), chicken bone (Fig. 1g) and nylon cylinder (Fig. 1h) are used as the