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Feasibility of electrical impedance tomography in haemorrhagic stroke treatment using adaptive mesh

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Abstract . EIT has been proposed for acute stroke differentiation, specifically to determine the type of stroke, either ischaemia (clot) or haemorrhage (bleed) to allow the rapid use of clot-busting drugs in the former (Romsauerova et al 2006). This addresses an important medical need, although there is little treatment offered in the case of haemorrhage. Also the demands on EIT are high with usually no availability to take a ‘before’ measurement, ruling out time difference imaging. Recently a new treatment option for haemorrhage has been proposed and is being studied in international randomised controlled trial: the early reduction of elevated blood pressure to attenuate the haematoma. This has been shown via CT to reduce bleeds by up to 1mL by Anderson et al 2008. The use of EIT as a continuous measure is desirable here to monitor the effect of blood pressure reduction. A 1mL increase of haemorrhagic lesion located near scalp on the right side of head caused a boundary voltage change of less than 0.05% at 50 kHz. This could be visually observed in a time difference 3D reconstruction with no change in electrode positions, mesh, background conductivity or drift when baseline noise was less than 0.005% but not when noise was increased to 0.01%. This useful result informs us that the EIT system must have noise of less than 0.005% at 50 kHz including instrumentation, physiological and other biases.

1. Introduction
Stroke is traditionally defined as the sudden onset of a focal neurological deficit lasting longer than 24 hours caused either by intracerebral haemorrhage or ischaemic infarction. It is the third most common cause of death in Australia. About one-third of victims will die within one month. Intracerebral haemorrhage (ICH) accounts for about 10% of all strokes but for a much higher percentage of deaths due to stroke. The principal cause of intracerebral haemorrhage is elevated blood pressure or ‘hypertension’. Bleeding disorders and use of anticoagulants are also increases causes of intracerebral haemorrhage. Control of risk factors is the key approach to management. Most patients with a stroke require urgent imaging to determine the cause and guide treatment. Investigation is with CT or MRI. Both can distinguish an ischaemic from haemorrhagic stroke, and other structural abnormalities or stroke mimics. Because the development of an acute stroke is a medical emergency, admission to a stroke unit and investigation as soon as possible is advised [1]. EIT has been proposed for acute stroke differentiation, specifically to determine the type of stroke, either ischaemia or haemorrhage to allow the rapid use of clot-busting drugs in the former [2]. This addresses an important medical need, although there is little treatment offered in the case of ICH. Also
the demands on EIT are high with usually no availability to take a ‘before’ measurement, ruling out time difference imaging [3].

One potential way to manage ICH is with early intensive blood pressure reduction. However, there is much uncertainty about the effects of early lowering of elevated blood pressure after acute ICH. Such an approach appears safe and feasible but a large scale trial is required to determine its effectiveness on substantive clinical outcomes to influence practice [4]. Electrical impedance tomography (EIT) may be appropriate for online-monitoring and control of blood pressure reduction without too much inconvenience for patients. A major methodological problem is the poor quality of the conductivity images, which is due to the low spatial resolution and low sensitivity for structures far away from the object’s surface as well as large qualitative errors in the reconstruction conductivity values. In this paper we report on a 3D simulation of ICH inside brain to investigate the feasibility of detecting changes in a haemorrhagic lesion located close to scalp.

2. Methods

The electric field was calculated at each node in the mesh using a linear finite element solver written in Matlab (the Math Works Inc., MA). Simulations using the UCL realistic head finite element method (FEM), associated head shaped tank eeg31b protocol, and tissue conductivities from the literature were used to assess the feasibility of EIT in these applications [5], [6], [11]. All meshes were constructed from linear, tetrahedral elements. We used ISO2MESH software and head and brain sample produced by Qianqian Fang for making one coarse and one fine mesh for forward and inverse solution [12]. The mesh for forward solution had 136387 nodes and 770660 elements and the number of nodes and elements for inverse solution was 61496 and 365481 respectively (figure 1).

![Figure 1. Left side image of mesh for forward solution with 770660 elements, Right side image of mesh for inverse solution with 365481 elements shown.](image)

The conductivity of the skull is that measured by Oostendorp [7], which is significantly higher than the value of Law [8]. The sensitivity at each node was calculated using Geselowitz’s theorem [9], [10]. The sensitivity matrix was created by performing the calculation for each node in the mesh and for all combinations of current injection and voltage measurement electrodes. In all cases, point electrodes were assumed, located at the node closest to the actual position of each electrode. The number of electrodes was 31 and the ground index supposed to be on the nose. The exact location of the electrodes has been shown in the figure 2. The diameter of each electrode considered 6.5 mm and the stimulation current source was 400 µA [11]. For evaluating EIT in detection of small changes of ICH, we created 1 ml haemorrhagic lesion close to scalp which is shown in figure 2 on the right side. This location was chosen from elements of brain which produced in smaller size in comparison with outside brain elements. The software that we used for image visualizing was MayaVi written by Prabhu Ramachandran. In order to make our simulation result closer to practical experience we added different percentage of noise to measuring signal. Uniformly distributed random noise was generated using the Matlab function ‘Rand’.
3. Results

An increase of 1mL ICH caused a boundary voltage change of less than 0.05% at 50 kHz. In figure 3 reconstruction of ICH with zero noise up to 0.003% noise has been shown. The reconstructed images with different noise input were used to compare ability of EIT systems for detection of ICH. It shows in figure 3 that a low noise EIT system can easily detect voltage changes near 0.05%. We changed the percentage of input noise between 0.001% and 0.01%. This observation has been done in a time difference 3D reconstruction without any change in electrode positions, mesh, background conductivity or drift. The experience demonstrated that in images with baseline noise up to 0.005% small changes in ICH can easily be detected by EIT systems. However, in images with 0.005% or more added noise, detection of small changes near 1ml is more difficult (figure 4). This useful result informs us that the EIT system must have noise of less than 0.005% at 50 kHz including instrumentation, physiological and other biases.

Figure 2. Left side Electrode positions, Black numbers are for EEG31b, red electrodes and numbers are spiral 16 protocol. Electrodes 6 & 7 are positioned 2cm inferior to O1 and O2. Right side location of 1mL Perturbation.

Figure 3. Reconstruction of 1mL perturbation top left no noise, top right 0.001% noise, bottom left 0.002% noise and bottom right 0.003% noise
4. Discussions

This is the first study demonstrating the feasibility of EIT in haemorrhagic stroke treatment. The main attraction of EIT is that it can be easily assessed non-invasively, at low cost and at bedside. EIT techniques can be used to visualize physiological activities in a human body such as respiration, cardiac circulation, brain function, stomach emptying, fracture healing, bladder filling, and others. An optimal treatment requires information on conductivity distribution inside a patient to design effective injection current patterns. EIT systems do exist that have instrumentation noise of less than 0.1% when measured in ideal conditions but not when measuring on a saline tank or real subject [13]. The white noise in this system including 2 more suitable systems for imaging epileptic seizures increased from about 0.03% on the resistor to 0.08% on the human. It increased with load but was independent of use of the multiplexer [14]. Major sources of error in MFEIT are the common mode phenomena, stray capacitances, common mode rejection and the mentioned transient effects due to the multiplexing which lead to a load dependence in the frequency response of systems[15], [16]. A distributed system with digitization at the electrode could be a next step in MFEIT system development. Overall, the results indicate that it is possible to extract small changes in ICH if we are able to decrease the noise level.

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