Bone Electrical Impedance and Tomographic Reconstruction of Fracture Detection: A Review

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Abstract—**Electrical Impedance Tomography (EIT) techniques elaborate two dimensions images from average spatial distribution of resistivity within a three-dimensional structure. In the fracture and healing process of long bones, the limb has changes of bioimpedance values. This paper review varius works in bone electrical impedance and tomographic reconstruction, and proposes potential improvements for clinical applications of the current technology to apply in first emergency attention in difficult access areas (p.e.: mountains areas).**

Keywords—**Electrical impedance tomography, osteography, bone fracture healing, transverse resistivity ratio, bioimpedance.**

I. INTRODUCTION

Electrical Impedance Tomography (EIT) techniques elaborate two dimension images from average spatial distribution of resistivity within a three-dimensional structure.

When a certain region is crossed by a constant current (frequency range between 10-100kHz and sinusoidal waveform), a complex potential is induced at the boundary, which depends on the regional distribution of resistivity. Sheffield's researchers produce in vivo images from measurements of the boundary voltage gradients followed by backprojection along equipotential lines [1].

This technique is used in clinical applications such as dynamic cardiac imaging, monitoring gastric emptying, pulmonary imaging, monitoring bone healing, and monitoring hyperthermia treatment, in inspite of having a spatial resolution of 5-10% of the diameter of the region [2].

This medical imaging method has some advantages such as being non-invasive, non-hazaradous, high speed-good temporal resolution, sensitive to very small impedance changes and inexpensive [3] and portable equipment.

The aim of this paper is to review the application of EIT in monitoring bone healing as studied by Aberbeen's researchers in the late 80s and early 90s and to propose possible applications and upgrades/improvements for clinical applications with the current technology.

II. LONG BONE FRACTURE

The diaphyseal region of long bones has a wide range of resistivities due to the presence of different tissues, blood a resistivity of 15MΩ and the bone an average resistivity of 150MΩ. Bones and muscles are anisotropic, being more resistive in their transverse section than their longitudinal section. Figure 1, derived from Geddes and Baker [4], shows the range of resistivities encountered.

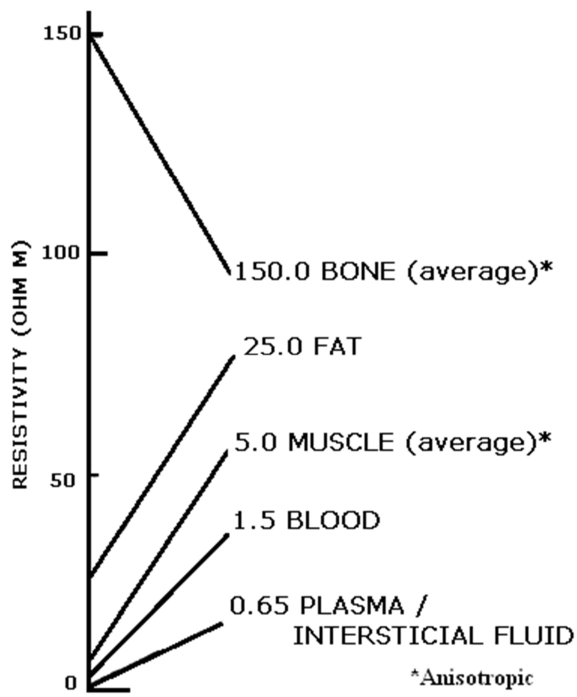

Fig. 1 Bioresistivity values present in human upper arm[2]

Immediately after a fracture, the bone healing process begins and it has three consecutive phases: the inflammatory phase (from 0 to 3 weeks), the reparative phase (from 3 weeks to 6 weeks) and the remodeling phase (more than 6 weeks to years).

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Once a diaphyseal fracture occurs, many measurable biopotential changes appear. In the inflammatory phase, while there is a highly conductive region in the plane of the fracture, the resistivity of the limb at the fracture site is very low, being similar to resistivity of blood (1,5MΩ), which is the major component at the fracture hematoma. The causes of resistivity changes are loss of integrity of high resistivity bone, creation of a conducting pathway between the fractured ends of the bone, collection of low resistivity haematoma at and around the fracture site, necrosis of the fractured ends leading to a phase of the inflammatory response with increased vascularity, exudation of low resistivity plasma like oedema fluid in the interstitial space of the surrounding tissue and increased local temperature, as well as varying degrees of damage and swelling of surrounding tissues, depending on the nature of the trauma.

In the reparative phase, the mass of bone producing cells rallies to produce cartilage, callus and bone This proliferation of cells should increase the resistivity in the region to normal bone levels (reference levels). The callus associated with the fracture is prolonged to remodeling phase. The external bridging callus allows the fracture to stabilize and begin the phase of remodeling.

In this phase, the newly formed bone adapts to its function of load bearing, and unwanted bone is removed. Dead bone that may be relevant to the structure of the limb is revitalized by recanalization with Haversian systems or replaced by creeping substitution, gradually recovering the electrical characteristics of the region.

III. THE ABERBEEN IMPEDANCE IMAGING SYSTEM

In the Aberdeen imaging system, 16 electrodes are placed in a split-array equidistantly around the limb (Figure 2). The current is driven through the bottom two electrodes as shown. The reference electrode is located diametrically opposed to the two driving electrodes. The voltage gradient is measured between the reference electrode and each pair of electrodes on either side of the reference electrode. The procedure is then repeated stepwise around the limb. Thus it is possible to build up a composite impedance image of the three-dimensional section of the limb [6][9].

A known current is driven through electrodes 'A' and 'E'. This sets up lines of current flow between the two electrodes. Along these lines, there are regions of equal potential, which run perpendicular to the current lines. A reference electrode, electrode C, is equidistantly located between electrodes 'B' and 'D'. If the current is being passed through an homogeneous medium, then the voltage gradient between 'C' and 'B', and 'C' and 'D' should be identical. However, if a subterranean fault should be present, this would alter the flow of the current and therefore the distribution of the equipotential lines. This will be manifested as a difference between the voltage gradients 'CB' and 'CD' [6].

Sixteen electrodes (made of Ag:AgCl) form the split array. Their size is 12.5mm x 25mm. In the fracture clinic, the electrodes are equidistantly placed on 25mm wide elastic electrode belts.

The induced boundary potentials are measured, demodulated, digitized, averaged and stored on a disk. Meanwhile, measurement and image reconstruction are controlled by a microprocessor.

The image reconstruction is on a 64 x 64 matrix.

The transverse resistivity ratio (TRR) was calculated in each case as the ratio of the average transverse potential gradient of the test limb to that of the contralateral normal limb at equivalent points [5].

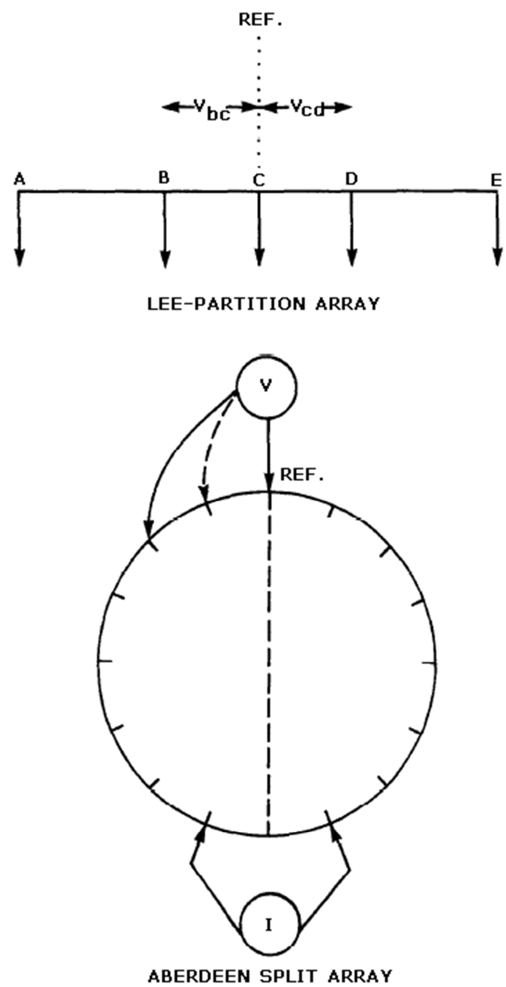

Fig. 2 Split array in Aberbeen impedance imaging system [6]

IV. Review of EIT applied to bone

A research group from Aberdeen University, Scotland, -headed by Dr. Vivek Kulkarni- published a series of articles between 1989 and 1995 that refers to the application of EIT to bone lesions in limbs (humerus [2][5], and tibia-fibula [6]), the improvement of The Aberdeen Impedance Imaging System [7] and a revision of EIT literature [8].

We focus mainly on the articles where the bone fracture of limbs is analyzed using the "Aberdeen Impedance Imaging System".

The obtained results are shown in Figures 3 and 4. Figure 3 shows the values measured in relation with the electrodes placed in the region of interest in the limb, and Figure 3a, the milivolts measured in each pair of electrodes under 3 different situations: healthy bone structure, bone structure 3 weeks after the fracture and bone structure 5 weeks after the fracture.

Figure 3b y 3c show the TRR already described in section III: 'The Aberdeen Impedance Imaging System' based on the measurements obtained from the pair of electrodes used. Figure 3b shows TRR various in very similar situations to 3 curves in healthy humerus, humerus 3 weeks post fracture –contralateral to the healthy arm in the same patient- and humerus 16 weeks post fracture – the same patient's arm now healthy after a fracture. Meanwhile Figure 3c shows the values of a healthy right leg (tibia and fibula), a fracture leg -3½ weeks post trauma-, a successful bone reparation and a bone reconstruction with no union of the segments separated in the fracture.

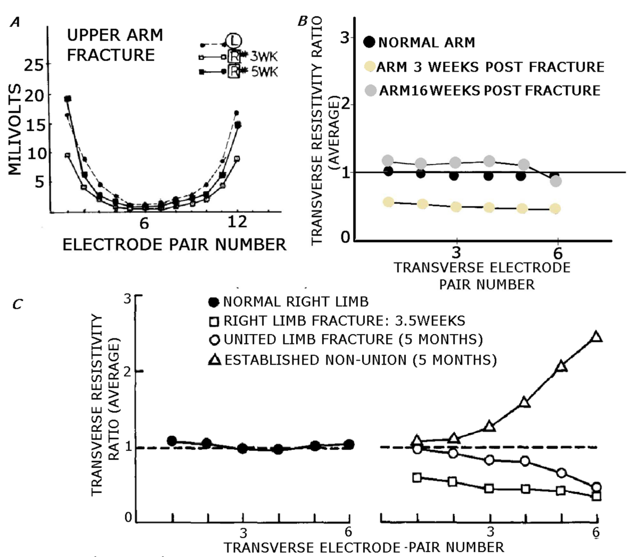

Fig. 3 Impedance measurements in a. humerus[2], b. humerus[5] and c. tibia and fibula[6]

Figure 4 shows the tomographic reconstruction images taking the impedance measurements as a starting point. These images are made of 64 elements high and 64 elements wide. The technology used for the control, processing and digital reconstruction was BBC microprocessor master series [10].

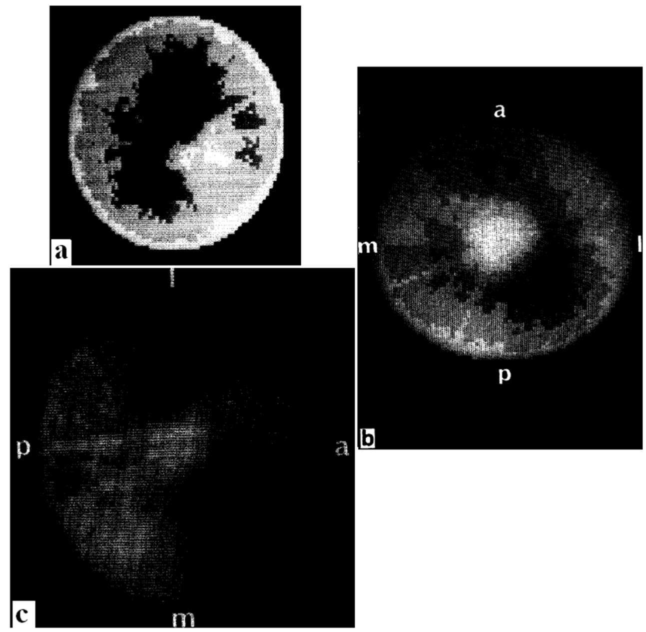

Fig. 4 Tomographic reconstruction of a. right leg, b. right upper limb and c. tibia and fibula [5]

V. Analysis of the results 2 decades later

The results obtained by the work group from Aberdeen University are specific and auspicious.

The measured values (specified in Figure 3) show, at a glance, that there is a variation in the values of bioimpedance in the different situations that can be present in a long bone structure: innate integrity, fracture, integrity after the recuperation and no union after a long recuperation period. These values were measured in the upper limb (humerus) as well as in the lower limb (tibias and fibula).

The tomography axial images reconstructed have no comparable quality and resolution with any of the current images method, either computerized axial tomography, X-Rays or nuclear magnetic resonance, but it is worth noting that the possibility of generating them exist. The difference between bone electrical impedance and others techniques is the mathematical problem that entails the image tomographic reconstruction with some boundaries values.

VI. Possible application and improvements

Una aplicación útil de un método portatil de monitoreo de fractura ósea es para emergencias de primera atención médica en áreas de difícil acceso, como pueden ser zonas de montaña.

The computerized technology used in the works done by the Aberbeen University group, is now obsolete. Taking into account the improvements achieved in the processing of signals and images with the development of microprocessors, Digital Signal Processors and daily use computers, the possibility of getting faster and more exact data is a direct interpolation.

It is also possible to do an analysis starting from the smaller electrodes to generate a boundary's electrode matrix around of one of the human limb that gives a huge quantity of measurable data.

Another possibility is getting measurements using a method different from The Aberdeen Impedance Imaging System, such as the adjacent drive method, the opposite method, the cross method or the trigonometric method [11]. We might also consider the possibility of injecting a current with different parameters.

There is a very complex possibility that would favor the whole EIT technique, and it is finding a new resolution method for the mathematical problem that allows for the reconstruction of the image.

At this time, these improvements proposed are being developed to be evaluated in the near future.

VII. Discussion and Conclusions

The revision of the usefulness of this method in this clinical application appears because of the possibility of getting an ultra portable diagnosis equipment of bone extremity damages (like a notebook plus an additional unit) to places where it is difficult or complex to go with a first emergency medical attention (mountain zone and adverse weather).

It is worth noting that no new contributions for this clinical application were found in the last 20 years, so this may mean that there were no works published.

Nevertheless, the greatest part in the EIT clinical applications is in progress and not many of them would be able to pass from the investigation lab to the production of biomedical equipment. It is for this reason that making an actualization in osteography could offer good results with specific effects and application for the daily use in the medical circle.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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