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The Study of Electrical Bioimpedanceon the Knee

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Abstract

Replacement of knee is an orthopedic operation. It is needed by hemophiliac patients. This operation involves the risk of blood loss and infection inside the knee. 100% replacement clotting factor must be maintained for at least 2 weeks. Based on this level, the hematological treatment must be carried out. Also pharmacokinetic parameters such as recovery and half-life, optimal doses and treatment time must be considered. The total knee replacement patients have a shorter lifespan than those with osteoarthritis. This Comparative Study examines the bio-mechanics of knee such as patient function, ligament retention and alignment. Analyzing the characteristics of joint loading, stress distribution and the biologic response of bone to stress will provide improve both function and implant longevity.

Keywords: Hemophiliacs, Osteoarthritis, Bio-mechanics

I. INTRODUCTION

Electrical bio impedance (EBI) is a technique that involves passing a small amount of electrical current through a volume of biological tissue, and measuring the ensuing voltage change across that tissue to calculate the passive impedance imposed against electrical current flow.

The electrical conductivity for different types of tissue varies; such EBI measures can provide information regarding the underlying structural composition of the tissue volume.

In the last 5 years, more than 50 research articles were published about Artificial Knee Replacement. We reviewed these articles and present some descriptive statistics in this paper, as well as a discussion about the major advancements and shortcomings.

For total knee replacement, 10-year implant survival rate was 95·6% (95% CI 95·3–95·9) and 20-year rate was 85·0% (83·2–86·6). For total knee replacement, 10-year implant survival rate was 96·1% (95·8–96·4), and 20-year implant survival rate was 89·7% (87·5–91·5. Our review revealed some shortcomings of the previous research. First, it remains unclear which position the patient is at that moment.

EBI is often measured at a single frequency of excitation—typically in the tens of kHz or higher to reduce losses due to the skin-electrode interface and also allow for higher safety limits on current levels of excitation—but can also be measured at multiple frequencies to allow for bioimpedance spectroscopy. EBI measurements that could potentially be used for quantifying knee joint health following an acute injury, in a wearable setting.

II. MATERIALS AND METHODS

A. *Bioimpedance Measurement Analysis*

A custom analog front-end is used to acquire static and dynamic bioimpedance measurements from the knee joint. Note that, “static”bioimpedance is considered the slowly varying component of impedance that would change based on structural modifications of the tissue volume(i.e., edema); “dynamic” bioimpedance, on the other hand, captures the mΩ level fluctuations in the tissue impedance that are cardio-synchronous, and associated with the blood volume pulse. The block diagram of the measurement setup is shown in the figure 1.1.

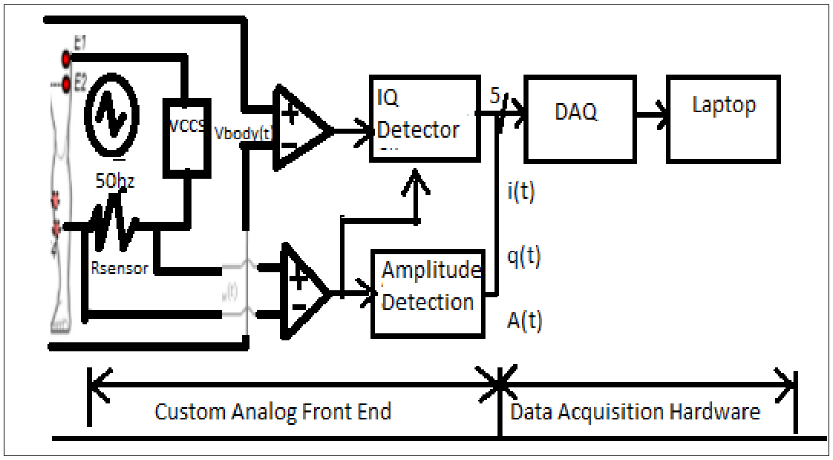

Fig. 1.1: A block diagram of the bioimpedance measurement system. E1-E4 represents the electrodes that interface to the body, where E1 and E4 are current electrodes, and E2 and E3 are voltage electrodes.

A sinusoidal current is input to the knee (frequency 50 kHz, and amplitude 2 mApp) via electrodes E1 and E4; the voltage drop resulting from this current excitation is detected from electrodes E2 and E3. The circuit also senses the delivered current to subsequently correct for any variability over time. An I/Q demodulator consisting of in-phase and quadrature phase sensitive detection and filtering is used to find both in-phase and quadrature components of the measured voltage. The signal is passed through amplitude detection to get the signal which is used to monitor the amplitude of the injected current. The signals are then recorded using a MP150 data acquisition system (Biopac Systems Inc., Goleta, CA) with a sampling rate of 2 kHz.

B. *Human Subject Studies and Measurement Protocols*

Five separate human subject studies were conducted to assess the bioimpedance measurement system and the designed algorithm. All human subject studies were approved by the Georgia Institute of Technology Institutional ReviewBoard (IRB) and the Army Human Research Protection Office (AHRPO).

1) *Discriminating Healthy versus Injured Knees and Monitoring Longitudinal Injury Recovery*

+In the first test performed, the bioimpedance measurement system was used to acquire measurements from 49 subjects. Out of these subjects, 42 were healthy, control subjects (27 male, 15 female) with no history of recent injury to any knee. Seven subjects (six male, one female) had a recent acute, unilateral knee injury (within one month before the measurement date), requiring subsequent corrective surgery.

Measurements were taken from both knees of each subject. Later, the in-phase and quadrature signals were amplitude corrected and calibrated to get the static resistance and reactance signals.

The mean of these signals over 60 seconds was taken to compute knee resistance and reactance of a given subject. This protocol was repeated on the seven injured subjects, on one occasion several months (4-7) after corrective surgery was performed.

2) *Day-to-Day Variability in EBI Measurements*

A second test was performed to investigate the day-to-day variability of the knee impedance measures. EBI measurements were acquired from five healthy subjects for three days within a week under standard conditions (e.g., no previous exercise and same time of day). The electrodes and electrode configuration in the first test were used and measurements were taken from both knees. Since the first human study indicated that the difference in resistance from left to right knee was an important parameter for separating healthy from injured knees, the day-to-day variability in this parameter in particular was quantified.

3) *Investigating Effects of Local Heating / Cooling on EBI*

A third test was performed for seven healthy subjects to investigate the effects of local tissue heating and cooling on knee bioimpedance. Tissue (skin and muscle) heating will decrease pre- to post-capillary resistance ratios thus resulting in net capillary filtration and increasing interstitial fluid, while local cooling will have the opposite effect is shown in figure 1.2.

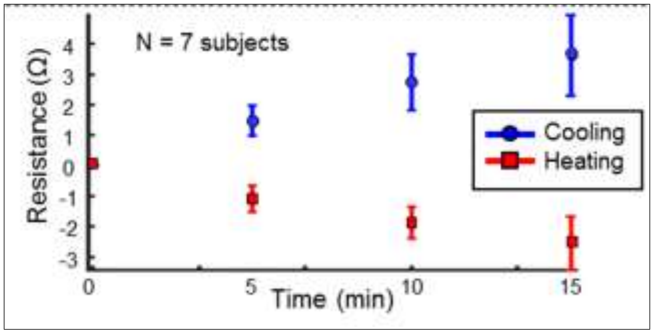

Fig. 1.2: Resistance vs Time.

In this test, the subject’s knee bioimpedance was recorded (with the same electrodes, electrode placement and subject positioning as thefirst test) while the knee was locally cooled using a standard ice-pack (Pro-Tec Athletics, Richmond WA) on the anterior patella for 20 minutes. Skin temperature on the patella was measured using a resistance temperature detector.

4) Evaluation of a Knee Wrap with Dry Electrodes Integrated

Experiments were performed on seven control subjects to demonstrate the usability of the bioimpedance measurement system with dry electrodes integrated into a knee brace. Then the subject was asked to wear the designed brace. The brace consists of two wraps, each containing the proximal (E1 and E2) and distal (E3 and E4) electrodes. The brace was positioned such that the electrodes were at similar positions tithe ones in the prior tests. Signals were acquired while the subject was still, in the same position for 60 seconds. The signals were amplitude corrected and calibrated to get the resistance and reactance signals measured using wet and dry electrodes. The measured resistance and reactance which was compared for wet and dry electrodes, was calculated by averaging the resistance and reactance signals over the 60 second time interval.

III. THE BIOIMPEDANCE SYSTEM ANALYSIS THAT HAS BEEN DONE BY OTHER AUTHORS ARE STUDIED BELOW

Table – 1
Comparative study of various references.

Paper Title	*Author*	*Year*	*Concept*	*Merits*	*Demerits*
Dry-contact and noncontact biopotential electrodes: methodological review	*Yu Mike Chi, Tzyy-Ping Jung, GertCauwenberghs*	*2010*	*This paper aims to critically address the latest developments in dry and non-contact electrodes accounting for both of these considerations. FET-input amplifier configured in unity-gain will be more than sufficient to buffer signals from virtually any electrode.*	*The basic principles behind gel-less electrodes are also well known. Despite decades of research in alternative bio-potential sensor technologies for ECG and EEG applications.*	*The lack of standard measurement methods combined with human variability makes an objective comparison scarce and difficult.*
Chest pulse-wave velocity: a novel approach to assess arterial stiffness	*JosepSol`a*, Olivier Ch´etelat, Claudio Sartori, Yves Allemann, and Stefano F. Rimoldi .*	*2011*	*Pulse-Wave Velocity (PWV) devices detect the arrival time of a pressure pulse and calculate the delay in pulse-arrival time between the proximal and distal sensors. By measuring the distance through which the pulse wave has propagated, one estimates a pulse-propagation-velocity value.*	*ICG signal is considered to be a good estimate of the opening of the aortic valve, and is referred to as B-point This method allows locating B-points even when no inflections are present in the ICG signals*	*The third derivative of ICG contains several misleading local maxima, and this approach is hard to be implemented in an unsupervised manner*
Artifact removal from the radial bioimpedance signal using adaptive wavelet packet transform	*Pranali C. Choudhari1, Dr. M. S. Panse*	*2014*	*A classical statistical technique for baseline cancellation can be used to suppress the artifacts, but it also subdues the beat-to-beat variations and tends to blunt the peak in the ICG. A linear time-varying filtering approach is undertaken to suppress the baseline drift in the ECG signal.*	*This is a nonlinear method, and its performance is based on estimation of reference points in the PR intervals. Method looks quite simple to implement.*	*This is a nonlinear approach so it is complex and highly dependent to beat rate calculations and becomes less accurate in low heart rates.*

IV. DISCUSSION

Dry-contact and noncontact bio potential electrodes: methodological review [1], by Yu Mike Chi, Tzyy-Ping Jung, Gert Cauwenberghs, aims to critically address the latest developments in dry and non-contact electrodes. The lack of standard measurement methods combined with human variability makes an objective comparison scarce and difficult stands as the major drawback. Chest pulse-wave velocity: a novel approach to assess arterial stiffness [2] reviewed by JosepSol`a*, Olivier Ch´etelat, Claudio Sartori, Yves Allemann, and Stefano F. Rimoldi in the year 2011, focuses on Pulse-Wave Velocity (PWV) devices that detect the arrival time of a pressure pulse and calculate the delay in pulse-arrival time between the proximal and distal sensors. This approach is hard to be implemented. In addition to that, the third derivative of ICG contains several misleading local. Artifact removal from the radial bioimpedance signal using adaptive wavelet packet transform [3], by Pranali C. Choudhari1, Dr. M. S. Panse in the year 2014, uses a classical statistical technique for baseline cancellation to suppress the artifacts. A linear time-varying filtering approach is undertaken to suppress the baseline drift in the ECG signal. This is a nonlinear approach so it is complex and highly dependent to beat rate calculations and becomes less accurate in low heart rates. Considering all the merits and demerits of the above cited papers by various authors, we describe a bioimpedance measurement system intended for wearable use, and demonstrate its ability to acquire physiologically relevant measurements from the knee joint. A position detection algorithm and the usability of the system were presented as a step towards reducing user guidance and making the system more feasible for a wearable setting. A web application is also developed for the easier access of doctors and patients irrespective of their location. The effective sensors- Flex and Force, are used to monitor the position of the knee and sensing the stress on the knee, respectively. When the subject is not in the desirable position, a buzzer alert is made. It also sends a message to the patient's registered mobile number that the patient is in danger. It includes the current, daily and monthly report of the patient and hence is helpful at the time of consultation. Thus, without much strain on his/her knee, the patient can monitor and keep a check on the pressure applied on the knee such that the operation heals completely.

V. CONCLUSION

Through this study, we analysed various previous year papers based on Electrical Bio IMPEDANCE. By carefully evaluating the merits and demerits, we describe a bio impedance measurement system intended for wearable use, and demonstrate its ability to acquire physiologically relevant measurements from the knee joint. A validation study, conducted to show the ability of the measurement system in detecting small changes in interstitial fluid volume due to local tissue heating or cooling, demonstrating the sensitivity of the measurement system. A position detection algorithm and the usability of the system were presented as a step towards reducing user guidance and making the system more feasible for a wearable setting.
Future efforts to develop a wearable system will focus on

1) Hardware miniaturization and integration into a knee braceand including textile electrodes rather than copper ones;
2) Applying this technology to other joints such as the shoulder;
3) Developing a system sufficiently robust for unilateralrather than bilateral use (i.e., without the need for comparingthe left to right knee);

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