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# Flexible concentric ring electrode for non invasive bioelectrical surface recordings

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**Abstract**

Non-invasive bioelectrical recordings are usually carried out by using monopolar or bipolar disc electrodes. The poor spatial resolution is one important disadvantage of this kind of electrodes tending to pick up physiological interferences. Concentric ring electrodes have already been implemented in rigid substrates to increase the spatial resolution in the recording of bioelectrical signals such as the electrocardiography (ECG) or the electroencephalography (EEG). Our goal was to develop and test a new modular active sensor made up of a disposable sensing part with concentric ring electrodes printed on a flexible substrate by thick-film technology connected to a battery powered signal conditioning circuit, and to compare it to rigid conventional concentric ring electrodes implemented on printed circuit board. Simultaneous ECG recordings were carried out using both flexible and rigid electrodes. Results show that flexible concentric ring electrodes present lower skin-electrode contact impedance, higher amplitude and lower baseline wander than the rigid ones



*Keywords:* flexible electrode; non invasive bioelectric signal; concentric ring electrode

## 1. Introduction

Bioelectrical activity is a spatio-temporal process which is spatially distributed over the three dimensions of organ system and evolves in time. It is of great importance to interpret the bioelectrical signals not only in the time domain but also in the space domain which consists in localizing bioelectrical sources which contribute to noninvasive electrical recordings such as electrocardiogram (ECG),

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electroencephalogram (EEG). However, the spatial resolution of the body surface potential recordings is still limited due to the smearing effect caused by the torso volume conductor and it could not be resolved by simple increasing the number of body surface recording electrodes [1]. In this respect, considerable efforts have been made to study the feasibility of body surface Laplacian electrograms to localize bioelectrical sources [2-3]. Theoretically, laplacian of surface potential is proportional to the derivative of the component of the current density orthogonal to the body surface. It can be interpreted as a filter that allocates more weight to the bioelectrical dipoles adjacent to the recording points and thus permits to attenuate the bioelectrical interference that propagates along the abdominal surface [4]. Laplacian potentials can be obtained by discretization techniques such as the five-point method proposed by Hjorth [5] and can also be directly estimated by means of concentric ring electrodes. He and Cohen were the first who used bipolar ring electrodes to measure the ECG Laplacian potential directly from the body surface [6]. Later on, Lu and Tarjan (2002) developed an active Laplacian sensor that consisted in tripolar concentric ring electrode in quasi-bipolar configuration (TCB), where the outer ring and the center disc were electrically shorted to study the applicability of this kind of electrodes to locally detect arrhythmia in real-time [7]. Active TCB electrodes have already been used to estimate the Laplacian potential of other bioelectrical signals such as the electroencephalogram (EEG), electroenterogram (EEnG) [3] and the electrohysterogram (EHG) [8].

Nevertheless the clinical application of Laplacian technique is still limited in spite of its numerous advantages. This is due to the fact that these electrodes have been implemented on rigid substrates which neither fit properly to the body surface curvature nor offer the necessary comfort in ambulatory applications as it happens with the electrodes presented in this work. Thus the goal of this work is to develop and test a new flexible active TCB electrode that adapts to the body surface curvature for recording non-invasive bioelectrical activity with high spatial resolution, so as to enhance the ambulatory applications of these electrodes.

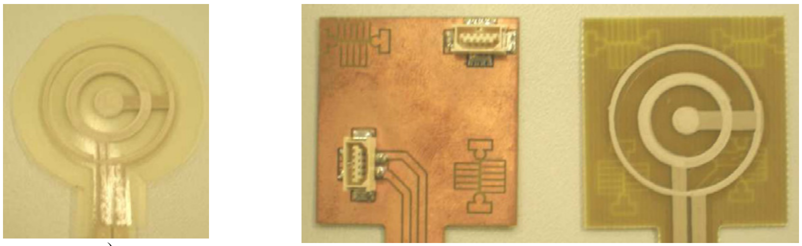
## 2. Materials and Methods

### *2.1. Electrode implementation*

The flexible active TCB electrode is made up of a disposable sensing electrode and a battery powered signal-conditioning circuit whose main characteristics were reported in a previous work [3]. The sensing electrodes consist of an inner disc and two concentric ring electrodes in bipolar configuration (TCB), i.e., the inner disc and the outer ring are shorted together (see Figure 1), this configuration provides an approximation to the Laplacian potential [2]. The flexible electrodes are implemented by printing biocompatible silver conductor paste onto a flexible substrate by thick-film technology. Heat seal dielectric paste was used in order to avoid short circuit between the two output signals. Several flexible and biocompatible screen-printing substrates (Valox FR-1, Poliester MelinexST506 and Ultem R16SG00) were used and assayed. Precisely it was valued the silver conductor and the dielectric paste adhesion to these substrates by using a sticky tape (8915 Filament APT 3M). On the other hand the skin-electrode contact impedance of these electrodes was also measured in 20 healthy volunteers, being the electrode placed in the same position. Flexible electrodes features were also compared with that of rigid concentric ring electrodes of same dimension implemented on conventional PCB (FR-4) substrate.

### *2.2. ECG recording*

Simultaneous ECG recordings were carried out using both flexible (Ultem, Fig.1a) and rigid (Fig. 1b) electrodes in 20 volunteers. Firstly the chest skin where electrodes had to be placed was exfoliated and cleaned to remove dead skin cells and to reduce the skin contact impedance. ECG recordings were obtained by placing next to each other flexible and rigid concentric ring electrodes on the chest surface in the area over the heart. An unipolar reference electrode was placed on the right hip of the subject. Both ECG signals were amplified, bandpass filtered between 0.01 Hz and 100 Hz and acquired at a sampling frequency of 1 kHz.



a) b)

Fig. 1. Flexible concentric ring electrode (left) and rigid one (right). Dimensions of both electrodes: inner disc (4 mm diameter), middle ring (12 mm inner diameter, 15.76 mm outer diameter), outer ring (22.76 mm inner diameter, 24 mm outer diameter).

## 3. Results

All tested flexible substrates showed good adherence with the silver and dielectric pastes: Dielectric paste takes off from polyester MelinexST506 after more than 30 cycles, whereas both conductor and dielectric pastes resisted in both UltemR16SG00 and Valox FR-1 for more than 50 cycles. Table 1 shows the electrode-skin contact impedance mean and standard deviation value for both flexible and rigid electrode in 20 volunteers. It is noteworthy that all flexible electrodes presented lower skin-electrode impedance than the rigid one, which may suggest a better skin-electrode contact can be achieved using flexible electrodes. Based on these tests, flexible electrode implemented onto UltemR16SG00 was selected for further ECG monitoring analysis thanks to easiness for screen printing and its slightly lower skin-electrode impedance (see table 1), although it is believed that similar results would be obtained if other substrates were used in ECG monitoring test.

Table 1. Electrode-skin contact impedance values for concentric ring electrodes implemented on different substrates. The electrode-skin contact impedance was measured for each substrate in 20 volunteers (12 men, 8 women)

| Screen-printing substrates | Electrode-skin Contact impedance (kΩ) |
|---|---|
| Valox FR-1 | 5.14±2.28 |
| MelinexST506 | 5.65 ±2.79 |
| UltemR16SG00 | 5.09±2.25 |
| Rigid substrate, PCB (FR-4) | 8.86±3.83 |

Figure 2 shows 15 s of simultaneous ECG recording corresponding to concentric ring flexible electrode (upper trace) and rigid electrode (lower trace). As it can be appreciated, fiducial points of cardiac activity can be picked up using both electrodes, being QRS complex amplitude acquired by flexible electrode higher than that of rigid electrode. In addition, ECG signal obtained by rigid electrode show a noticeable baseline wander.

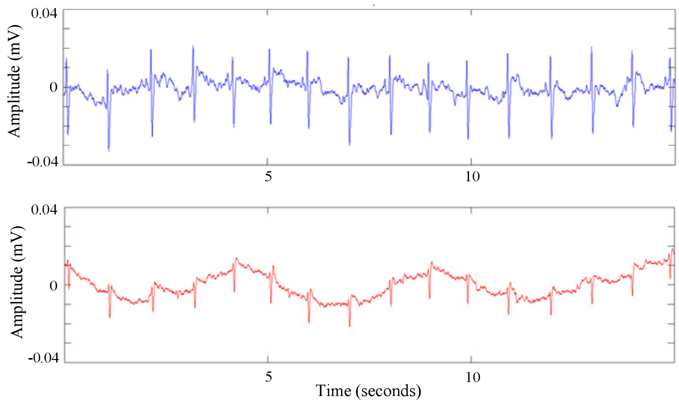



Fig. 2. Simultaneous ECG recordings using flexible (top) and rigid (bottom) concentric ring electrodes. The signal provided by the flexible electrode is of higher amplitude and presents lower baseline wander than that of the rigid one.

## 4. Conclusions

Flexible concentric electrodes provide lower skin-electrode impedance than the rigid ones, which is probably caused by a better skin-electrode contact. Cardiac activity can be picked up with these new flexible electrodes. Precisely, ECG recordings from flexible electrodes present higher QRS complex amplitude and lower baseline wander than that of concentric ring rigid electrodes. To sum up, the new flexible electrodes combine the comfort of the existing disposable electrodes, with the high spatial sensitivity of concentric ring electrodes

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## References

[1] Lian J, Li G, Cheng J, Avitall B and He B. Body surface Laplacian mapping of atrial depolarization in healthy human subjects. *Med. Biol. Eng Comput* 2002; **40**: 650-659

[2] Koka K and Besio WG. Improvement of spatial selectivity and decrease of mutual information of tri-polar concentric ring electrodes 2007; *J. Neurosci. Methods* **165**: 216-222

[3] Prats-Boluda G, Garcia-Casado J, Martinez-de-Juan JL, and Ye-Lin Y. Active concentric ring electrode for non-invasive detection of intestinal myoelectric signals. *Med. Eng Phys* 2011*;* **33**: 446-455

[4] Wu D, Tsai HC and He B. On the estimation of the Laplacian electrocardiogram during ventricular activation. *Ann. Biomed. Eng* 1999; **27**:731-745

[5] Hjorth B. An on-line transformation of EEG scalp potentials into orthogonal source derivations. *Electroencephalogr. Clin. Neurophysiol.* 1975; **39**:526-530

[6] He and Cohen RJ, Body surface Laplacian mapping of cardiac electrical activity. *Am. J. Cardiol.* 1992; **70**:1617-1620

[7] Lu CC and Tarjan PP. An ultra-high common-mode rejection ratio (CMRR) AC instrumentation amplifier for laplacian electrocardiographic measurement. *Biomed. Instrum. Technol* 2002; **33**:76-83

[8] Li G, Wang Y, Jiang W, Wang LL, Lu C-YS and Besio WG. Active Laplacian Electrode for the Data-acquisition System of EHG. *Journal of Physics: Conference Series* 2005: **13**, 330-335