



# Writing a review paper on concentric ring electrode technology

Oleksandr Makeyev<sup>1</sup>, Larry Moore<sup>1</sup>, Alana Benally<sup>1</sup>, Yiyao Ye-Lin<sup>2</sup>, Gema Prats-Boluda<sup>2</sup>, Javier Garcia-Casado<sup>2</sup>

<sup>1</sup>Diné College, Tsaile, AZ; <sup>2</sup>Universitat Politècnica de València, València, Spain



## Introduction

The expansion of knowledge concerning concentric ring electrodes (CREs) allowed for enhanced clinical applications and improvements to key parameters of electrophysiological measurements such as signal-to-noise ratio, spatial resolution, and selectivity. These accomplishments are related to the ability of CREs to estimate the second spatial derivative of a measured potential, the Laplacian. While previous work has covered studying various aspects of optimizing CRE configurations, comparing different CRE and disc electrodes, applications of CREs to numerous areas of electrophysiological measurement, and manufacturing techniques and considerations, no work to date has compiled the available literature into a comprehensive review for ease of access and synthesis of this technology's diverse applications. This conceptual context presents considerations involved into writing such a review of CRE technology. A detailed outline structuring our review paper in accordance with the most important aspects of electrode design and applications and a process for sorting and distilling papers on CREs as contributions to outline sections for later assembly into a cohesive manuscript were developed.

## Methods

The review paper's structure (Fig. 1) will consist of the following major sections background, design considerations, implementation, applications, and cutting edge and future work. Each major section consists of multiple subsections. For example, applications section is separated into subsection corresponding to electroencephalograms, electrocardiograms, electrohysterograms, electromyograms as well as recordings from intestines, bladder, etc. Moreover, subsections are further subdivided into subsubsections. For example, subsection on electromyograms is further subdivided into applications related to diaphragmatic, masseter, swallowing, general skeletal muscles, MUAPs as well as removal of artifacts. Compared to some of the other established linear approaches to structuring review papers such as PRISMA, our approach offers the advantage of offering researchers in different areas a clear pathway to the portion of the review most relevant to their specific field.

### Review paper's outline structure

1. Background:
    - a. Laplacian Potential
    - b. Approximation of Laplacian
    - c. CREs without Laplacian approximation
  2. Design:
    - a. CRE configurations and Laplacian estimation
    - b. Laplacian accuracy: number of rings, their size, and inter-ring distances
    - c. Effect of CRE configuration on signal characteristics:
      - i. Attenuation of distant sources/sensitivity (Veil et al. 2021)
      - ii. Mutual information, signal-to-noise ratio, spatial selectivity
      - iii. Spatial resolution
    - d. Modeling: negligible dimensions model versus finite dimensions model
    - e. Non-Laplacian based design considerations (Veil et al. 2021)
  3. Implementation:
    - a. Concentric hooks versus concentric rings
    - b. Rigid versus flexible substrates
    - c. Materials
    - d. Fabrication technologies/techniques (Veil et al. 2021)
  4. Applications:
    - a. EEG
      - i. Epilepsy
        1. Transcranial Focal Stimulations
  - effectiveness: rats; cats
    1. Transcranial Focal Stimulation, safety: skin; memory; brain
    2. Seizure onset detection
    3. High-frequency oscillations and seizure onset zone detection
  - ii. Brain-computer interface
  - b. ECG
  - c. EHG
    - i. Effects of fat and muscle thickness on signal attenuation
  - d. EMG
    - i. Diaphragmatic
    - ii. Masseter (bruxism)
    - iii. Swallowing
    - iv. General skeletal muscle
    - v. MUAPs
    - vi. Artifacts
  - e. EEnG
  - f. Bladder
    - i. Transurethral impedance spectroscopy (Veil et al. 2021)
5. Cutting edge and future work:
  - a. Partial shorting between rings due to salt bridges
  - b. Different/multiple optimization criteria based on finite dimensions model
    - a. Ultra-flexible CRE
    - b. Clinical validation, definition of "normal pattern" in healthy patients, advantage vs. bipolar recording using pair of disc electrodes

Figure 1. Outline of the review paper's structure.

## Preliminary Results

The sorting and distilling process for relevant CRE papers starts with individually reviewing them. Next, applicable sections, subsections, and subsubsections of the outline to which current paper belongs are identified. Finally, brief summaries are written individually for each subsubsection highlighting the most relevant aspects and contributions of the paper as related to that specific subsubsection. These summaries serve as building blocks of the resulting subsubsections, which in turn form subsections, and, ultimately, sections of the resulting review paper.

For example, the article entitled "Minimally Invasive Sensors for Transurethral Impedance Spectroscopy" by Veil et al. (2021) contributed to the following four paragraphs corresponding to different sections of the review paper's structure (Fig. 2).

- 2.c.i. Comparison of CRE and a square array of single circular electrodes in transurethral impedance spectroscopy shows the latter results in a twice higher percentage of negative sensitivities within the volume (Veil et al., 2021). Moreover, depth wise negative sensitivities reach nearly four times deeper into the tissue.
- 2.e. Alternative CRE configuration designs not related to Laplacian estimation include (Veil et al., 2021) that keeps the surface area the same for all the recording surfaces to facilitate utilization of ratios of voltages and currents for calculation of sensitivity. Instead of being used for Laplacian estimation, four elements are used as two pairs of current-carrying (central disc and outer ring) and voltage-measuring (two inner rings) electrodes.
- 3.d. In (Veil et al., 2021) miniature CRE sensor was fabricated via laser direct structuring and drilling of liquid crystal polymer followed by metallization with Cu/Ni/Au and milling.
- 4.f. Transurethral impedance spectroscopy for uro-oncological purposes has been studied in (Veil et al., 2021). This study found that CREs are superior to a square array of single circular electrodes in terms of sensitivity distribution within the volume beneath the sensors based on finite element method modeling. Moreover, they are also superior in terms of reproducibility of obtained results on ex vivo pig bladder data which fit the empirical Cole-Cole model for tissue impedance. Even though only healthy tissue has been utilized in this study, frequency range of 1 kHz to 1 MHz was proposed to be especially promising for detection of physiological and structural changes in cancerous tissue due to negligible electrode polarization.

Figure 2. Example of brief summaries written for (Veil et al., 2021) as related to different sections of the review paper's structure.

## Discussion

While this is not a research project in the strictest sense a substantial amount of research has been involved in developing both a detailed outline and a process for sorting and distilling papers and insights gained may turn out to be useful to others planning to take on a similar task in their field. Moreover, the process of writing a review paper as well as its main component of familiarizing oneself with up to a hundred journal papers on CRE technology published over the course of the last two decades turned out to have an additional benefit of increasing the research capacity via skill development related to distilling scientific publications to their core findings as well as to structuring and integrating large bodies of scientific knowledge.

## References

Veil, Carina, Simon Petillon, Jonas Hotz, Andrea Knöller, André Zimmermann, and Oliver Sawodny. 2021. "Minimally Invasive Sensors for Transurethral Impedance Spectroscopy." *IEEE Sensors Journal* 21 (20): 22858–67. <https://doi.org/10.1109/JSEN.2021.3108779>.

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