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# Comparison of Three Right-Unilateral Electroconvulsive Therapy Montages

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*Abstract*— **The efficacy and cognitive outcomes of electroconvulsive therapy (ECT) on psychiatric disorders have been shown to depend on variations in electrode montages. Conventionally, the right-unilateral (RUL) montage was temporoparietal, originally proposed by d'Elia. Although it was reported to have better cognitive outcomes than the bitemporal montage, it is still associated with substantial memory side effects. Two other RUL montages utilizing a frontal electrode, also proposed by d'Elia, may be more beneficial. In order to investigate this, a high resolution finite element human head model was generated from MRI scans and implemented with tissue heterogeneity. The model was used to compare the effects of three different d'Elia RUL montages. The results suggest that the two alternative placements are likely to result in lesser memory side effects, and may have useful efficacy.**

## I. INTRODUCTION

Electroconvulsive therapy (ECT) has been known as one of the most effective treatments for treatment-resistant depression. It is also used as a treatment for patients with other severe psychiatric disorders including bipolar disorder, psychosis and schizophrenia [1], [2]. Contemporary ECT generally involves passing biphasic brief-pulse currents transcranially into a patient under anaesthesia, producing a generalized seizure [1]. It has demonstrated that the degree of treatment efficacy as well as side effects is dependent on electrode configuration. Right-unilateral (RUL) ECT has been shown to cause less short-term memory loss than bitemporal (BT) ECT, but is less clinically effective when given at the same electrical dose relative to seizure threshold [3], [4]. Alternatively, some (but not all) studies have found that bifrontal (BF) ECT causes fewer memory side effects than BT ECT [5]–[8]. In addition, recent clinical research has found that TP-RUL had large effects on heart rate [9], [10], presumably due to direct stimulation of vagal nuclei in the brainstem [11].

In the quest for an appropriate RUL montage, d'Elia originally proposed three different placements [12]: temporoparietal RUL (TP-RUL) which is widely accepted today, frontofrontal RUL (FF-RUL) and frontoparietal RUL (FP-RUL). The latter two were abandoned, as it was more difficult to elicit seizures in some patients with these montages [12]–[14]. This may be due to the prevalent treatment methodology at the time, when ECT was given with fixed parameter settings on ECT machines delivering constant voltage. Given that the frontal bone of skull is much thicker than the temporal bone, the resistance is higher with the FF-RUL and FP-RUL montages, and thus missed seizures were more common [12]–[14], leading to the gradual widespread adoption of the TP-RUL placement. Nowadays, constant current machines are adopted for ECT application, and electrical dosing for patient is determined for each individual, based on empirical estimation of his/her seizure threshold. Thus, it is now possible to induce effective seizures with the FF-RUL and FP-RUL montages, and the efficacy and cognitive outcomes may be superior with these two placements compared to the commonly used d'Elia placement, but this has been minimally investigated.

In this study, a finite element (FE) model of the human head based on magnetic resonance imaging (MRI) data was utilized to compute the electric field (E-field) distribution in the brain. The objective of the study was to compare the effects of three d'Elia RUL montages using this anatomically-realistic head model.

## II. METHODS

The FE head model was reconstructed from T1-weighted MRI data of a healthy 35-year-old male subject, obtained from Neuroscience Research Australia (NeuRA, Sydney). Scan resolution was 1 mm in every direction. The details on segmentation and mesh generation were listed in Bai et al. [15]. The resulting mesh model consisted of 1,126,135 elements.

All compartments of the head model were assigned with isotropic conductivities, except for the white matter, details in Bai et al. [15]. ECT electrodes were defined mathematically as circular regions of radius 2.5 cm on the scalp [11]. Three montages used in d'Elia [12] were simulated: each utilising two electrodes placed on the scalp, as shown in Fig. 1:

- TP-RUL placement: one electrode (B) was placed 3 cm superior to the midpoint of a line connecting the right external ear canal with the lateral angle of the right eye, and the other electrode (A) placed just right of the vertex of the head.
- FP-RUL placement: one electrode (B) was placed 5 cm superior to the midpoint of the arcus superciliaris on the right, and the other electrode (A) was placed near the vertex, the same as electrode A in TP-RUL placement;
- FF-RUL placement: one electrode (B) was placed on the forehead, the same as electrode B in FP-RUL, and the other electrode was (A) placed 5 cm above electrode B.

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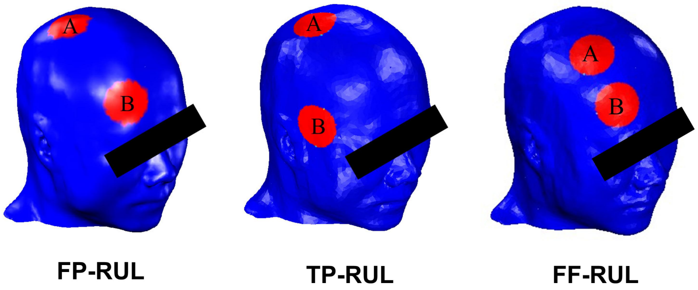

Fig. 1. Three d'Elia electrode placements: temporoparietal right unilateral (TP-RUL) placement, frontoparietal right unilateral (FP-RUL) placement and frontofrontal right unilateral (FF-RUL) placement. 'A' and 'B' are labels for the separate electrodes in each placement. To respect the subject's privacy, the eyes of the model are hidden.

All head compartments were simulated as volume conductors using Laplace's equation $\nabla \cdot (-\sigma \nabla \varphi) = 0$, where $\sigma$ is the tissue conductivity, and $\varphi$ is the electric potential. The boundary conditions were:

- active electrode boundary (electrode A): the inward current density normal to the boundary set to $J_n$, where $J_n = \frac{I}{\text{area of electrode}}$ [11], and the total injected current $I$ was fixed at 800 mA;
- return electrode boundary (electrode B): inward current density set to $-J_n$;
- distributed resistance boundary (at the base of the neck): outward current flow with assumed ground 3 cm below the boundary. This was to simulate a small proportion of the stimulus current that may be able to flow into and out of the torso, even though the net current flow through this boundary was zero;
- all other external boundaries were assigned as electric insulators (zero normal component of current density);
- continuous current density across all interior boundaries.

The models were solved using COMSOL (v3.5) on a Windows 64-bit workstation with 24 GB RAM utilizing 4 processors. To solve the stationary equations, a direct linear solver was utilized with an absolute error tolerance set to $10^{-5}$. It took $\sim$ 20 minutes to solve for the simulation.

Simulation results were analyzed by comparing the difference in the E-field distribution in the brain among different electrode montages and different head models. The analysis also focused on comparing the average E-field magnitude $\overline{E}$ in several regions of interest (ROIs) in the brain. The average E-field was calculated using the following equation:

$$\overline{E} = \frac{\int\limits_V |\mathbf{E}| \, \mathrm{d}V}{\int\limits_V \mathrm{d}V}, \tag{1}$$

where $|\mathbf{E}|$ is the magnitude of the E-field in the ROI in question, and $\int\limits_V$ represents a volume integral over this region. Note that the denominator integral is simply the volume of the ROI.

In addition, the term "accessibility" of the stimulus current was adopted to examine the proportion of current reaching into the brain. It was defined as the percentage of current injected into the brain to the total stimulus current.

## III. RESULTS

Fig. 2 shows the E-field magnitude profile over the surface of the whole brain for the three different ECT montages, and Fig. 3 show the brain E-field magnitude in various coronal and horizontal slices.

For the three RUL models, all of their E-field profiles presented right-side predominance characteristics. The current in the TP model appeared to largely spread over the right side of the brain, with higher E-fields on the frontal, temporal and parietal lobes, as well as the anterior part of the CB and brainstem. In the FP placement however, current was concentrated primarily in the frontal and parietal lobes of the right hemisphere, while sparing most of the temporal lobe. Also, the current shifted slightly towards the medial part of the brain. In comparison, the current with the FF placement was mostly confined to the right frontal lobe, as a result of placing both electrodes towards the front.

Table I lists the average regional E-field magnitude for the three ECT montages. As shown in the table, the right hemisphere magnitude was significantly greater than that in the left under the three RUL montages. The average E-field magnitude in the cerebellum and brainstem (CB) was higher in TP than in the other two montages. The montages with a frontal electrode resulted in a stronger E-field in the right dorsolateral prefrontal cortex (DLPFC). The E-fields in the right orbitofrontal cortex (OFC) were comparable among the three montages, with TP slightly higher than the other two. The FP placement induced a relatively higher E-field magnitude in the anterior cingulate cortices (ACCs) compared to the other two placements. In terms of the hippocampus, the TP placement, having a temporal electrode, resulted in a relatively high E-field in this region. Furthermore, the FF placement in general generated the lowest E-field magnitude in the brain (except in the right DLPFC) among the three d'Elia RUL montages, presumably due to an extremely low accessibility of the stimulus current, as shown in Table II.

## IV. DISCUSSION AND CONCLUSION

The unilateral ECT electrode configuration is commonly placed on the right side of the head. Since for the majority

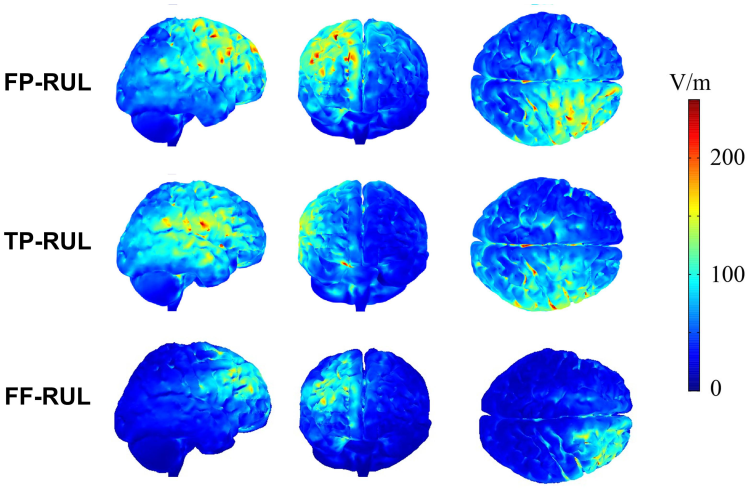

Fig. 2. E-field magnitude distribution for three ECT montages: temporoparietal right unilateral (TP-RUL), frontoparietal right unilateral (FP-RUL) and frontofrontal right unilateral (FF-RUL). The leftmost, middle and rightmost columns feature the lateral view from the right, the frontal view and the top view, respectively.

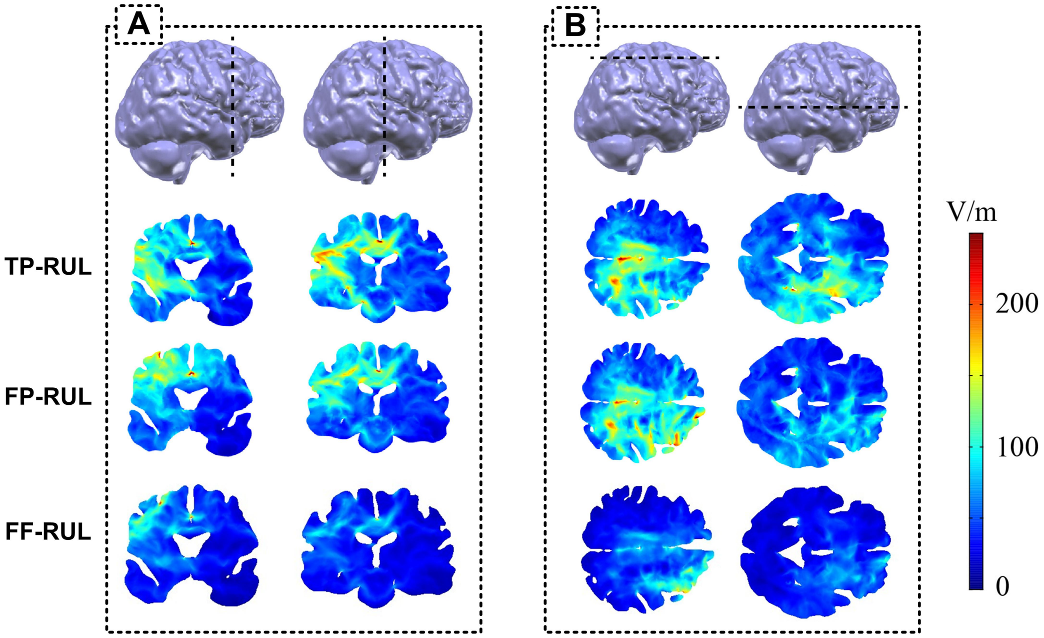

Fig. 3. E-field magnitude distribution in two coronal slices (panel A) and horizontal slices (panel B) for three ECT montages: temporoparietal right unilateral (TP-RUL), frontoparietal right unilateral (FP-RUL) and frontofrontal right unilateral (FF-RUL). Dashed lines indicate locations of slice planes.

of people, the left hemisphere of the brain is the dominant side for the control of speech and memory, a RUL montage will thus exert less effect on verbal memory [16]. RUL ECT montages have been shown to significantly reduce confusion and memory disturbance after the treatment, compared to the traditional bilateral montage, namely the BT electrode configuration [3], [4], [17], [18]. It is assumed that a smaller amount of electric current is delivered into the brain in unilateral montages [19], especially in the hippocampi, which are associated with memory consolidation. However, as shown in recent studies, even though the influence of the stimulus current on the left hippocampus was indeed weaker with TP-RUL than that with BT, the stimulation effect on the right was still comparable between the two [20]. In addition, the recent finding, that TP-RUL is most likely to induce effects on heart rate among the three conventional montages (BF, BT, TP-RUL) [9], [10] possibly due to its interaction with the brainstem [11], suggested that TP-RUL may not necessarily be the best option for a RUL montage.

Simulation results above showed that compared to the TP placement, both FP and FF produced comparable (or even stronger) E-field magnitudes in the DLPFC and ACC, both of which are considered to play important roles in the depression network [21]. In addition, both FP ECT and FF

TABLE I

Average brain regional E-fields (V/m)

| Compartment | TP-RUL | FP-RUL | FF-RUL |
|---|---|---|---|
| Left hemisphere | 41.50 | 41.90 | 27.40 |
| Right hemisphere | 67.22 | 62.55 | 43.41 |
| CB | 39.53 | 30.95 | 19.70 |
| Left DLPFC | 34.06 | 48.43 | 33.69 |
| Right DLPFC | 71.67 | 94.91 | 89.02 |
| Left OFC | 29.75 | 36.54 | 22.40 |
| Right OFC | 62.03 | 60.62 | 55.08 |
| Left ACC | 59.65 | 67.20 | 57.95 |
| Right ACC | 66.04 | 70.80 | 61.44 |
| Left hippocampus | 42.47 | 37.25 | 27.80 |
| Right hippocampus | 59.06 | 49.69 | 38.93 |

TABLE II

Accessibility of the stimulus current (%)

| ECT montage | Accessibility |
|---|---|
| TP-RUL | 57.35 |
| FP-RUL | 54.67 |
| FF-RUL | 36.14 |

ECT generated a lower E-field strength in the hippocampi, as well as in the CB and brainstem, compared to TP ECT. The simulation results of this study thus indicate that frontal placements may be better candidates for a RUL montage, i.e., provide similar efficacy with lesser memory impairment. Nevertheless, it may appear from the results that FP ECT holds an advantage over FF ECT, due to the fact that FP ECT had a much higher current accessibility. The low accessibility of the stimulus current with FF ECT was likely a consequence of a close inter-electrode distance, which resulted in a high degree of current shunting. Therefore in practice, a larger amount of electrical dose is needed to reach a patient's seizure threshold, and a higher voltage may be required to keep a constant current output. As a result, the patient may be susceptible to the possibility of skin burns, or more likely, due to voltage limiting associated with modern ECT devices as a safety precaution, the delivery of high voltage through a high impedance montage may lead to the failure of an effective stimulus being delivered [22], [23]. Future work including simulations using head models from different subjects and clinical trials is needed to verify the potential benefits of the alternative placements.

## V. Acknowledgment

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