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Influence of Aspect Ratio on the Current Density Profile of Recessed Stimulation Electrodes

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Introduction

Electrical stimulation is a therapeutic technique aimed at restoring impaired biological functions by injecting a controlled amount of charge in the body. Commonly used planar stimulation electrodes exhibit a non-uniform current density distribution (*j*) that can lead to locally exceeding the safe stimulation threshold [1]. An electrode can be recessed into an insulating part, which may result in a different *j* [2], thus a different injection of charge, which can induce damage or insufficient stimulation. However, few studies [3] have considered the influence of the recess parameters on *j* and how it could be used in electrode design.

Materials & Methods

A finite element model was used to calculate *j* at recessed and non-recessed planar disc platinum electrodes in saline in response to an applied potential (COMSOL 54 Electrochemistry module). The model is focused on the stationary primary *j*, neglecting kinetics effects and concentration gradients. A uniform potential (0.6 V) is applied to the electrode-electrolyte boundary and the electrical ground was set at the outer boundary, far away from the electrode surface. The current density magnitude was evaluated at several virtual points placed in the electrolyte (see scheme below) and normalized to the electrode center value (r=0). Recess shape (tubular and conical) and aspect ratio (AR), defined as recess depth divided by electrode diameter, were varied.

Fig. 1 : j at electrode surface, tubular recess vs. no recess

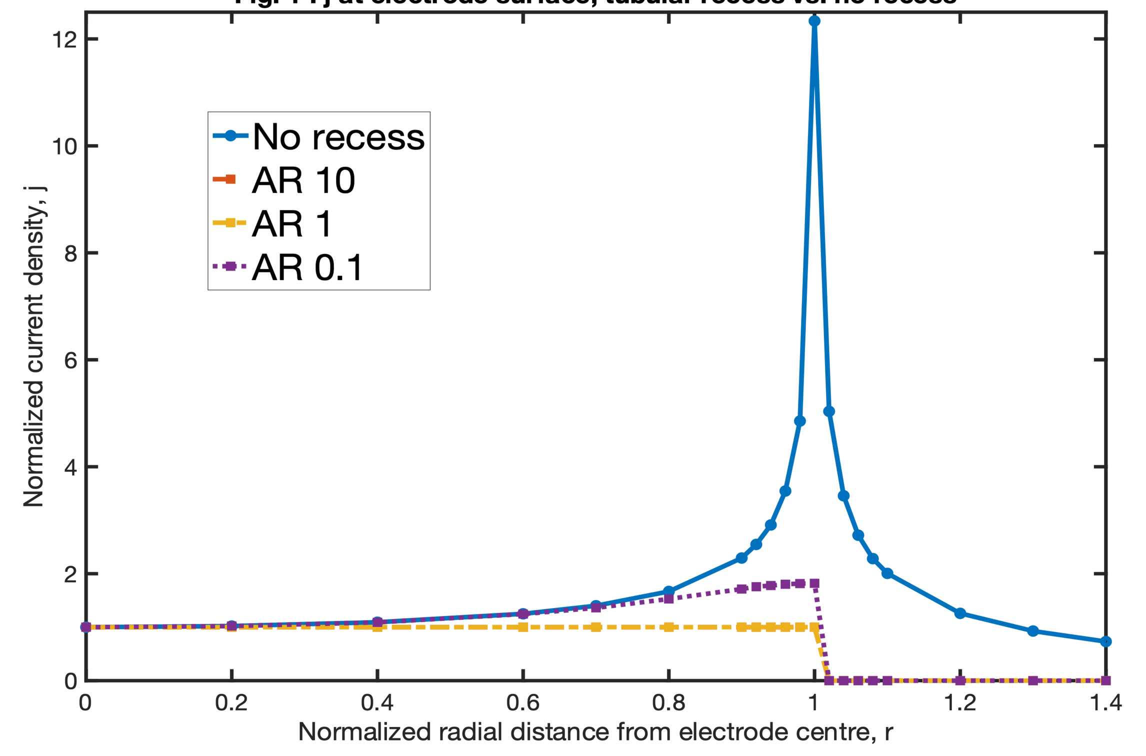


Fig 2. : j at electrode surface, conical recess vs. no recess

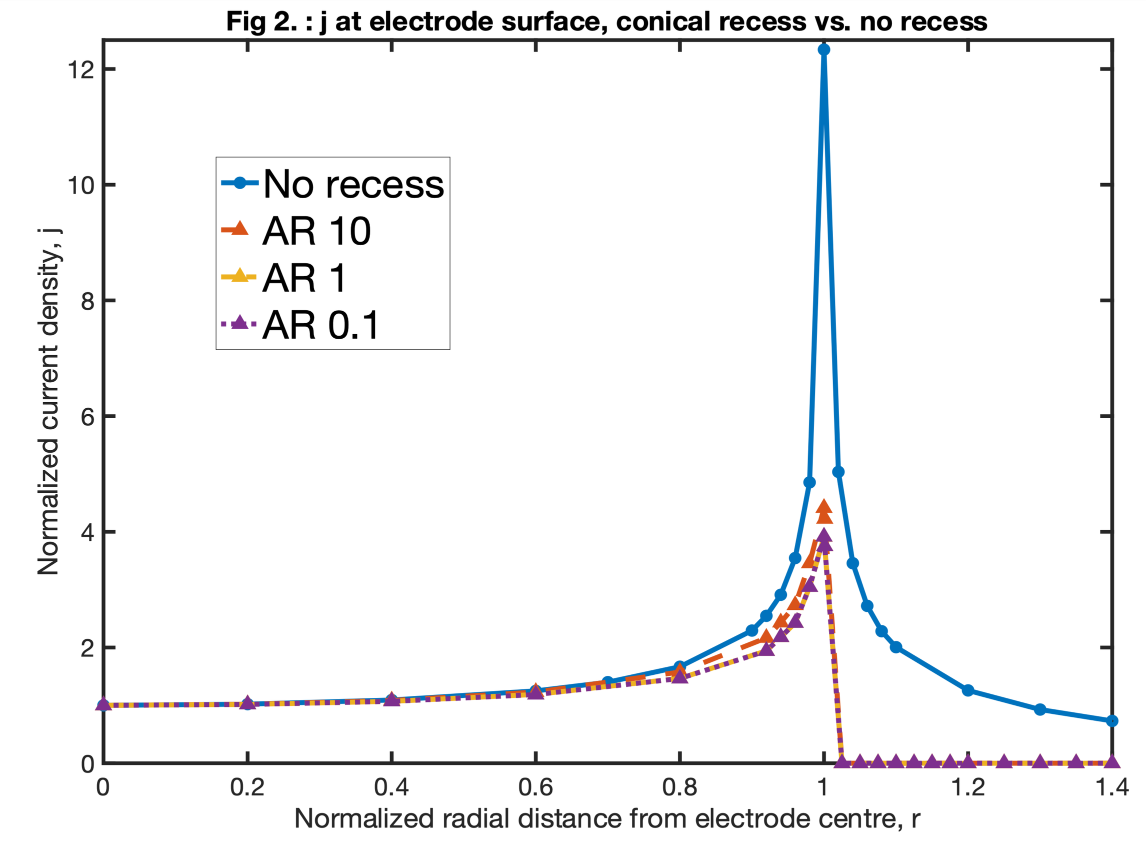
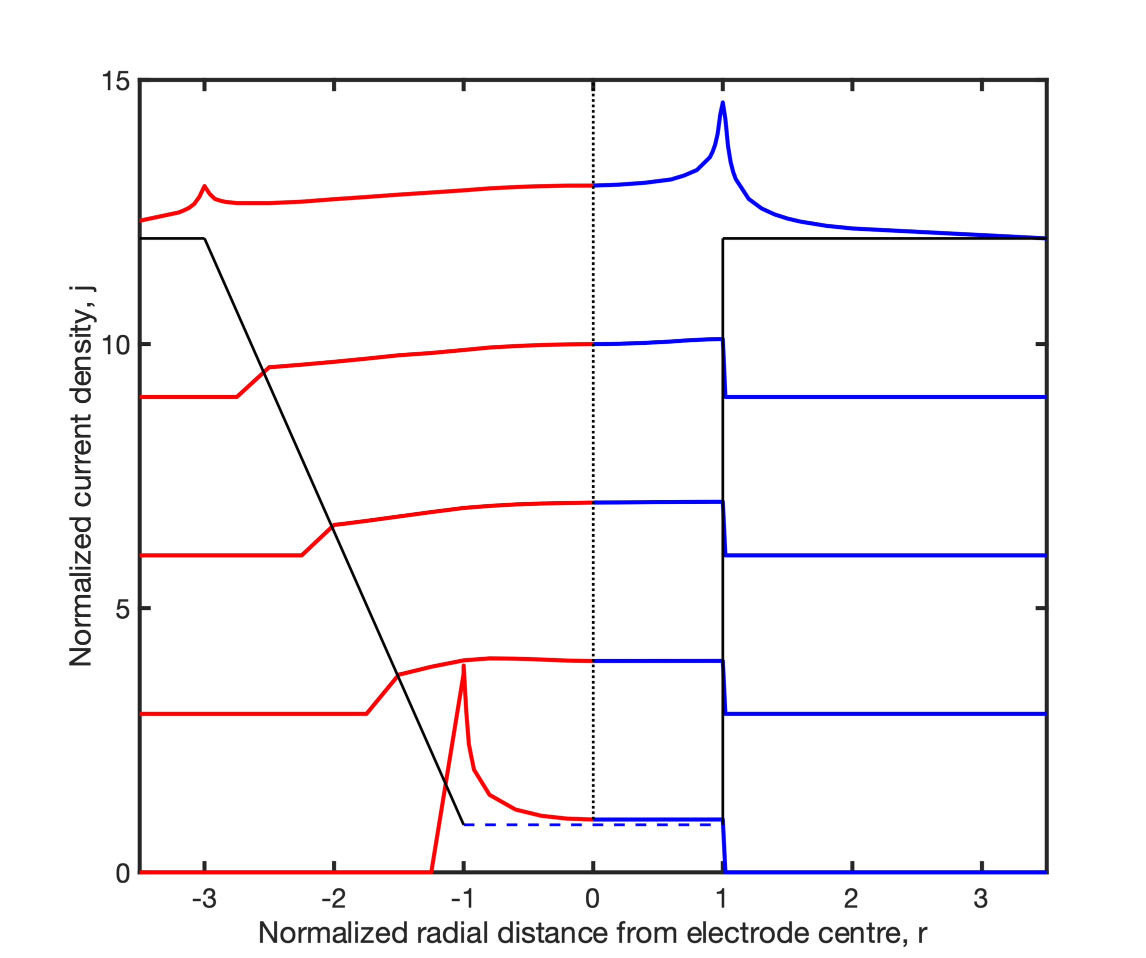


Fig. 3 : j along the recess for a conical (left) and a tubular (right) recess.



Profile at Electrode Surface

The current density was evaluated 1 µm above the electrode surface. On *Fig. 1*, the tubular recess shows a uniform profile compared to a non-recessed electrode, especially at AR 1 and 10. At AR 0.1, the vicinity of the open end of the recess explains the higher current density at the edge, which is still 6 times lower than for a non-recessed electrode. On *Fig. 2*, the conical recess presents a profile similar to a non-recessed electrode, with a 2.5 times lower peak at the edge. The AR does not influence the distribution at the electrode surface for the conical recess.

Table 1 shows the robustness of the results, despite varying the electrode and recess dimensions. It supports that the AR is the driving factor for this behavior, rather than the geometrical parameters taken separately.

Profile Along the Recess

The tubular recess keeps a uniform profile along the recess (*Fig. 3*), due to parallel current lines, until the open end, where it acts as a remote non-recessed electrode, with a 5 times smaller peak value. The conical recess profile becomes more uniform further from the electrode surface, showing even a slight decrease towards the recess wall.

At the end of the recess, a higher current density is also measured at the edge, but remains 2.5 times smaller than for a tubular recess.

Localisation	Electrode surface			End of the recess		
Aspect Ratio (AR)	**0.1**	**1**	**10**	**0.1**	**1**	**10**
Av. rel. std tub. (%)	0	0	0.05	0.39	0.27	0.13
Av. rel. std con. (%)	0.08	0	0.04	0.01	0.11	0.06

Table 1 : Relative standard deviation (std) of j for three different dimensions for each AR, for tubular (top) and conical (bottom) recesses. The std was calculated at each point of the profile and then averaged.

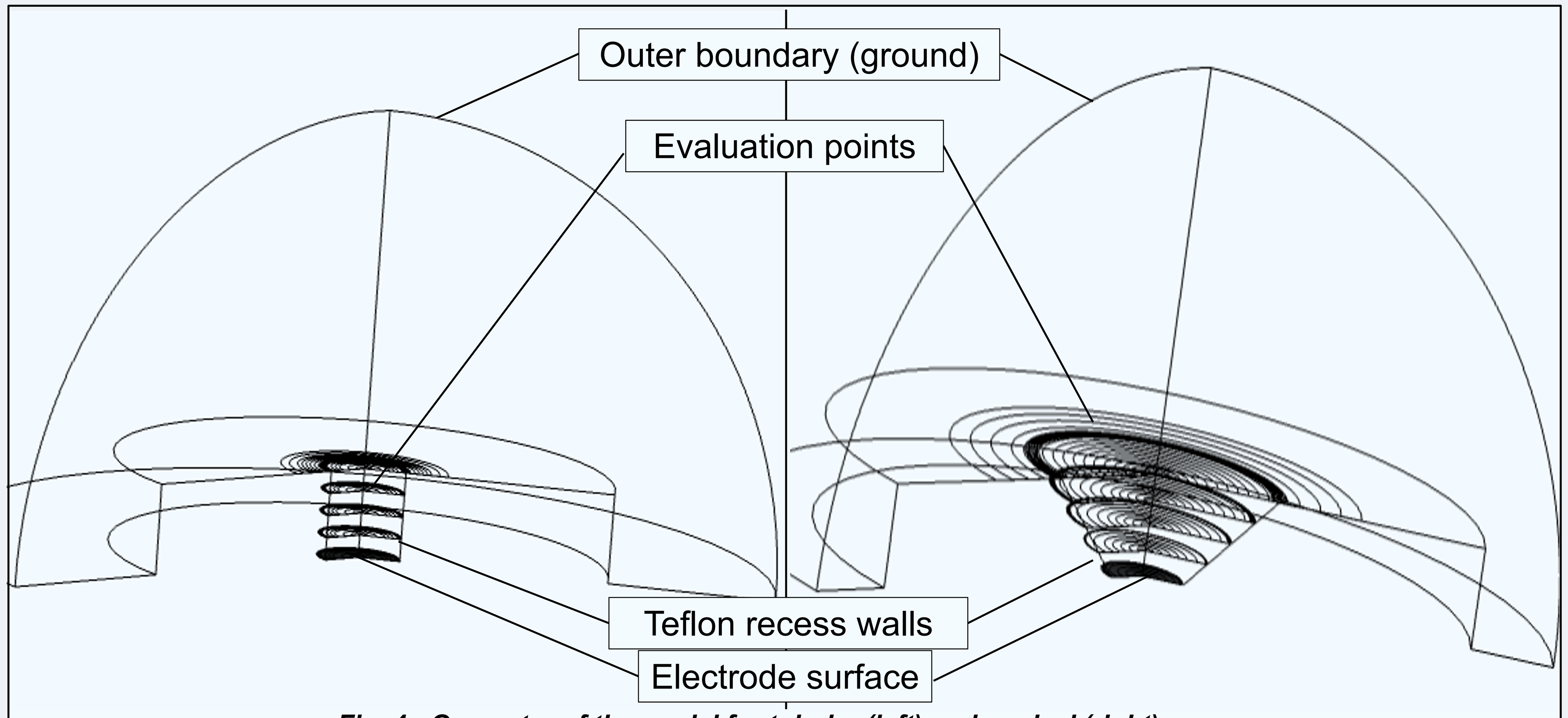


Fig. 4 : Geometry of the model for tubular (left) and conical (right) recess.

Conclusion

The AR greatly influences the *j* distribution around the electrode but the patterns are stable and enable the prediction of the current density in the solution. Carefully choosing the recess type and AR allows to control the *j* profile around the electrode.

Each recess has a zone with greater non-uniformity, corresponding to the maximum curvature of current lines : the recess opening for the tubular and the electrode surface for the conical. Varying the AR changes the proximity of this zone. Hence, a small AR will bring the zone closer, perturbating the *j* distribution.

Acknowledgements

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