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CORRESPONDENCE

Standardizing connectome-based brain tumor surgery through a network-based surgical nomenclature

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Intra-axial brain tumors exist within complex neural circuitry which when damaged during resection can lead to severe cognitive morbidity [1]. As such, there has been a growing interest for many in the neurosurgical community to consider the presence of large-scale brain networks in brain tumor surgery [2, 3]. Through significant advancements in high-throughput approaches and neuroimaging techniques, the anatomy of large-scale brain networks has now been detailed in a way which can be utilized in the clinical space [4]. However, in light of the complex nature of this structural–functional anatomy, a way to compare results, describe outcomes, and grade tumors in network-based neuro-oncological surgery has yet to be described. As in most fields even outside of neurosurgery, appropriate nomenclature and methods for communicating results are critical for replication and sharing findings between studies. As a first step, we introduce in this article a useful nomenclature which may expand our ability to standardize our communication and study of connectome-based brain tumor surgery.

The most important components of brain networks which are clinically actionable for neurosurgeons at the current time consists of considering a network's major (1) hub of brain regions and (2) interconnecting white matter bundles [2]. Thus, a simple scheme we propose consists of identifying the relationship of the tumor to these individual connectomic elements for each major brain network as shown in Fig. 1. In relation to each of these connectomic elements, a graded score can be provided according to how close or severe the network disruption is on a continuous scale. Then, for each network, a total score can be created by combining the individual scores obtained for the major fiber bundle and for each hub of brain regions (Fig. 1A–F). We refer to this scale as the "Sughrue-Ivan" nomenclature, and provide an example in Fig. 1G. These scores can be obtained prior to surgery, but also dynamically adjusted intraoperatively according to changing surgical plans. According to radiological scans after surgery, a postoperative score can be obtained for comparison with presurgical scores which may allow for (1) linking immediate functional outcomes with network presence, (2) prediction of the clinical pattern of disease in the postoperative course, (3) targeting for postoperative rehabilitation.

This scale provides a method and a means for others to begin to address the specific problem of what happens when multi-part cortical-based networks are damaged in brain tumor surgery. As shown in Fig. 1 and detailed elsewhere [1, 2, 5], the salience network (SN), central executive network (CEN), default mode network (DMN), language network, dorsal attention network (DAN), and ventral attention networks (VAN) are all multi-part networks with multiple hubs of cortical regions distributed in various different brain regions which are not directly adjacent to one another. Thus, although there exists other networks which also likely affect postoperative functional outcomes in brain tumor surgery, they were not included in this scale because they are relatively located in a single region to the extent that which they are understood, such as the motor, auditory, and visual systems. Furthermore, it is also important to consider that although a variety of methods can be used to obtain information about brain networks, this scale in particular computes a graded score based on tractographic analyses obtained from structural MRI [6].

Given the often heterogenous terms utilized to describe the same two network elements, a single uniform nomenclature provides us a number of important benefits moving forward. Considering the architecture of large-scale brain networks can dynamically inform presurgical targeting (e.g., "eloquent" regions), intraoperative decision making

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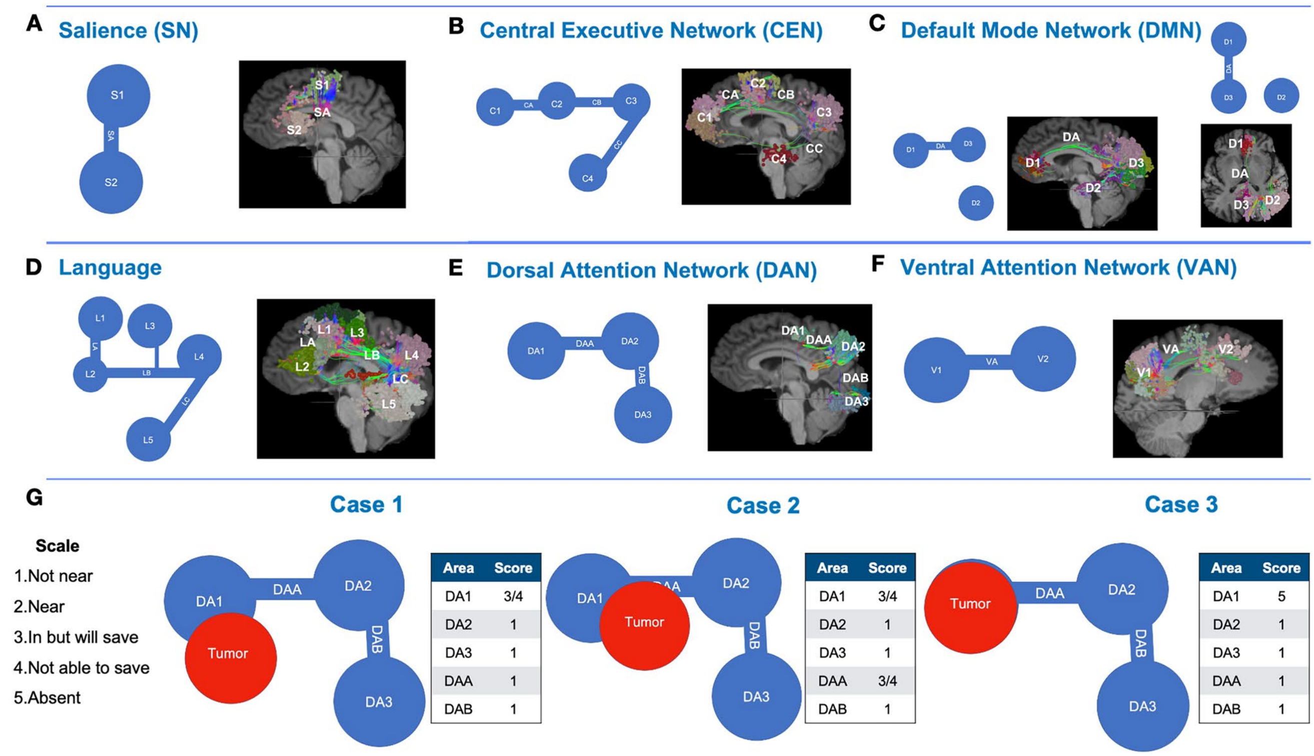

Fig. 1 Nomenclature for network-based neuro-oncological surgery. Panels **A**–**F** demonstrate a wire diagram for 6 major brain networks. The networks consist of two major components: (1) major hub regions and (2) interconnecting white matter bundles. For each network, the tumors relation to these connectomic elements are graded on a continuous scale according to how near or within the tumor is to the hubs or white matter bundles of the network. Panel **G** presents an example of grading three cases of a tumor in relation the dorsal attention network (DAN) (as in panel **E**) in different amounts. In case 1, the tumor is located near the frontal component (DA1) of the DAN, but not near the adjacent white matter bundle (DAA). DA1 receives a grade of 3 or 4 given it is unclear if it can be saved intraoperatively, while DAA and the other network components receive a score of 1. Differently, in case 2 the tumor envelopes both the frontal DA1 component and adjacent white matter tract DAA, both receiving a score of 3 or 4. Lastly, if the tumor completely envelops a network component such as in case 3 with DA1, a score of 5 is received

(e.g., functional boundaries of resection), and postsurgical decision making based on the predicted clinical pattern of disease (e.g., network-based rehabilitation). Most importantly, it will also improve our ability to understand the importance of brain networks in neuro-oncological surgery so that we can expand their utility in our surgical thinking to improve cognitive morbidity and mortality.

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Declarations

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