Dynamic functional backbones of brain networks during anesthetic state transitions

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Understanding consciousness is a topic of current interest in the neurosciences. Network analysis of brain activity in different states of consciousness is one technique to approach this problem. General anesthesia is a unique method to reversibly suppress consciousness. It alters states of consciousness and provides a model for dynamic changes in brain networks.

We propose a quantitative method to study dynamic brain networks. We define network backbones as the most probable subgraphs in the series of a brain network. In order to identify network backbones, we first extract a dynamical network series, which is a series of static networks that correspond to a given time point. Next, we identify all possible subgraphs from the network series, which consist of with the minimal number of links found in the network series. Finally, we obtain the most frequent subgraphs through dynamical network series as network backbones. We can then study the functional circuit time-series by tracing the appearance of backbones, or alternatively visualize the functional backbones' rank transition.

We measured the inter-regional brain activities as high-resolution time-series using electroencephalogram (EEG) from anesthetized patients during surgery (n=9 induced with propofol, n=9 induced with sevoflurane) at Asan Medical Center. Patients were categorized into two groups based on the anesthetics used. We used low-pass filtered electroencephalograms (<35Hz) across five states of consciousness from baseline consciousness to general anesthesia to recovery (baseline / induction / anesthetized / recovery / post-recovery). Network series were obtained by treating EEG channels as nodes, and inverse of normalized phase synchrony indices between nodes with 6-second time windows and 250-millisecond moving size as links. The top-12 functional backbones of dynamic brain networks were derived from each state.

The functional backbones of brain networks were categorized as ‘constitutive backbones’ which are present during all states, and ‘variable backbones’ which appear during specific states. Network backbones show the anesthetic-specific difference between propofol and sevoflurane induction. There were also robust network backbones unaffected by anesthetics, whereas some network backbones occurred only in the baseline state or anesthetized state, respectively. Our data suggest that there exist state-dependent network backbones in the brain corresponding to each state, even for general anesthesia.
Figure. 1: Examples of dynamic network backbones. This diagram illustrates how to extract backbones and their dynamics from dynamical network series. The first row is a series of original dynamical networks. The other rows are network backbones extracted from the original network series. The network structure retain at least for one epoch. The number of links for a backbone is fixed as the smallest network size (3 for this example) appeared in given series of original networks.

Figure. 2: Example of dynamical network backbones from a patient with sevoflurane. The network backbones are sorted in the order of appearance. New network backbones emerge as the patient state transitions across five anesthesia stages. Each stage is divided by green line.
The back dots indicate the appearance of a network backbone. It demonstrates state-specific network backbones. Some type of backbone only appears in a specific state: induction, anesthetized and recovery state. After capturing each backbone candidate, baseline state and post-recovery state show similar backbone time-series pattern, whereas the induction, anesthetic and recovery process shows unique patterns. Also there is transition of network backbone time-series along the recovery of consciousness point (blue line).

**Bibliography**


