ANY theory of consciousness will be incomplete unless it includes an explanation of the phenomenon of general anesthesia. Arguably, the most important contribution that the discipline of anesthesia can make to science will be in explaining the neurobiological mechanisms underlying the phenomenon of consciousness. The somewhat unobtrusive article by Lee et al.1 in this edition of Anesthesiology marks a substantial step forward in our understanding of consciousness. If the results are confirmed by subsequent work, this article will achieve a landmark status. The authors have done a small study, simply collecting multichannel electroencephalographic data from patients during induction with ketamine; and compared the results with those from a previously published study on propofol and sevoflurane inductions.2

Unsurprisingly, they found that ketamine anesthesia increased the power in the high frequencies in the electroencephalogram; whereas, sevoflurane or propofol—both of which act on different molecular targets—produces almost the opposite electroencephalographic effects (a decrease in the high frequencies and increase in low frequencies). This is the reason that the existing electroencephalographic monitors of general anesthetic drug effects—such as the bispectral index—are unable to reliably detect the actions of N-methyl-D-aspartate-blocking drugs such as ketamine and nitrous oxide.

If we were to merely look at the dominant frequencies in the electroencephalogram, we might conclude that there is no single “final common mechanism” for general anesthesia.

However, Lee et al. then looked more deeply into the spatial relationships hidden within the electroencephalographic data. They applied some sophisticated signal analysis and showed that—even though the raw electroencephalograms of the three groups looked quite different apparently—all three groups of anesthetic drugs in fact caused a very similar inhibition of information flux from the frontal area to the parietal region. The implications are that intact frontoparietal connectivity is a necessary requisite for the wakeful state. Conversely, disruption of frontoparietal feedback may be the final common network mechanism that is pathognomonic for unresponsiveness.

As usual, this work builds on previous results. The most directly comparable early work was done by Imas et al.3 who showed similar anesthetic suppression of frontoposterior information flux in animal studies. Recently there has been a burgeoning literature demonstrating anesthetic-induced breakdown in cortical connectivity. This has been estimated using a variety of quite different experimental and signal processing techniques, and applied to multichannel electroencephalography or functional magnetic resonance imaging data.4–6 A good case can be made that...
the primary function of the brain is to generate “meaning” from information flux. For more than 10 yr, Tononi has been refining and developing the information integration theory of consciousness. Although many details are still unclear, there seems to be accumulating evidence that the brain’s capacity for consciousness relies on high-order cortical information integration. It is intuitively easy to envisage propofol or sevoflurane causing periods of neuronal hyperpolarization and silence, and hence suppressing information flux within the brain. The article by Lee et al. is the first to show comparable disruption of frontoparietal information integration in the presence of an active cortex, as is found during ketamine anesthesia.

This work is still at an early stage and there are numerous issues that need to be resolved. Electrical activity is not the same thing as information. Can features of the averaged, smeared, and distorted electrical activity obtained from the scalp electroencephalogram reasonably represent information flux within the brain? Amazingly, this article indicates that it may be possible. The second big problem is to discover the best index. The terms “connectivity,” “coherence,” “feedback,” and “synchrony” have multiple definitions of varying usefulness. In some frequency bands—notably the α band—the spatial coherence markedly increases after loss of responsiveness. Interestingly, Tononi’s theory predicts the loss of responsiveness caused by hypersynchrony. What is the most robust signal analysis method? What particular regions of the scalp are important? The next few years will determine the answers to these questions; but it seems likely that the next generation of electroencephalographic anesthesia monitors will need to go beyond single-channel frequency analysis and incorporate some index of how well distant regions of the brain are talking to each other.

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