2025 MEDICAL STUDENT WINNING ESSAY –

GENERAL ANESTHESIA AND QUANTUM MECHANICS: A SOLUTION TO THE HARD PROBLEM OF CONSCIOUSNESS

By Ronny Thomas, University of Toronto

The goals of general anesthesia during medical procedures include the safe and reversible induction of paralysis, analgesia, amnesia, immobility, and unconsciousness.[1] Despite the prevalent use of general anesthetics for these purposes, there is still uncertainty surrounding the mechanisms of their actions on the human body and mind. In particular, how anesthesia induces a loss of consciousness is not well understood.[2] Recently, a theory that has received increased coverage by popular science media is Orchestrated Objective Reduction (Orch-OR).[3] This is a controversial theory posited by Nobel laureate physicist Roger Penrose and anesthesiologist and professor at University of Arizona Stuart Hameroff, that argues that quantum processes in microtubules play a role in the experience of consciousness and that anesthesia disrupts these microtubules leading to unconsciousness.[3]

Philosophically, the conscious mind has often been seen as separate from the body. Take Descartes for example: According to his famous statement "cogito ergo sum" (I think therefore I am), the existence of anything can be doubted, even the entirety of the external world and one's own body. But we can know that our mind exists, for without it we could not doubt our existence. Thus, Descartes draws a distinction between mind and body, resulting in what is known as Cartesian dualism.[4]

The problem with Cartesian dualism, however, is that neuroscience has shown that mental states are correlated with neural activity.[5] Current trends in neuroscience thus opt for a perspective on consciousness grounded in scientific materialism, arguing that consciousness is an emergent property of complex brain processes that are integrated together, and are thus, based in the physical matter of the body. Global Workspace Theory and Integrated Information Theory are examples of theories that attempt to explain the phenomena of consciousness in this manner.[6,7]

However, the philosopher David Chalmers argues that material explanations for consciousness may have strict limitations. Chalmers argues that there is no explanation for why consciousness occurs. A person may look at a tree, and a scientist may be able to trace the neural pathways in the brain that transmit this information, but Chalmers argues that the subjective experience of "tallness" or "greenness" or "treeness" cannot be understood from brain activity.[8] He goes further to demonstrate this idea by constructing what he calls "philosophical zombies." Imagine human beings who look and behave exactly as humans do, but without any subjective sensory experience. The synaptic and electrical activity in their brains would be exactly like normal humans, but they would have no sense experience. The fact that these beings are possible to conceive of implies that subjective experience is different from the physical processes in the brain.[9] This so-called "Hard Problem of Consciousness" indicates that although Cartesian dualism is flawed, consciousness cannot be entirely explained by our current understanding of neuroscience.

Due to this weakness of traditional methods of explaining consciousness, Roger Penrose decided to propose a new mechanism grounded in abstract mathematics. For some background, in 1931 the mathematician Kurt Godel published his incompleteness theorem, which states that there are some things that are true but cannot be proven within a rigorous framework.[10] For example, consider the Godel sentence "this statement cannot be proven true." If this statement is provable, then it is inconsistent. But if it is not provable, then it is true, but its truth cannot be proven.[10] The larger implication of Godel's Incompleteness theorem is that any formal proof system (such as those used to run computer algorithms) has 'holes' that cannot be patched through formal proofs alone. However, Penrose noticed that human mathematicians could prove things that formal proof

...continued on page 18

...continued from page 17

systems cannot, through the use of intuition or insight. Thus, he posited that the human mind runs a "non-computable algorithm," different to that of machines or traditional neuroscientific theories on brain activity. He then proposed that quantum mechanics could be the source of this non-computable algorithm within the human mind.[11]

Specifically, Penrose posited that the wave function could be a possible explanation for certain aspects of consciousness. The wave function is a mathematical description of the state of a quantum system. It's also a superposition of different states (called eigenstates), and it has a unique property that when interacting with a classical system (i.e., when an observer measures it), it collapses into one of its eigenstates (this is the source of Schrodinger's cat, which is both dead and alive until you open the box it is in). However, this results in an inherent randomness, which is unhelpful in describing consciousness, as it is evidently non-random. To modify this theory, Penrose argued that at the smallest level of reality (the Planck length), there are blisters of spacetime which each have their own wave function, and due to the effects of gravity and the inherent properties of spacetime, collapse in a non-computable but also non-random way, resulting in the theory he called Objective Reduction.[11] However, he still lacked a physical mechanism in the brain to ground this theory in human physiology, and for the most part, this theory was not taken seriously.

This is where anesthesiologist Stuart Hameroff's expertise was crucial. In the 1970s while he was an undergraduate working in a cancer lab, he became fascinated with microtubules and as an anesthesiologist, wondered if they played a role in human consciousness.[12] At the time, there was some research on the topic,[13] but not much consideration was given to this new and radical idea. Yet, due to his unique experiences in research as well as his clinical expertise in anesthesiology, Hameroff became convinced that the key to the human mind had something to do with microtubules.[12] After reading 'The Emperor's New Mind' (1980) by Roger Penrose and learning about the Objective Reduction theory, he reached out to him and together they worked to propose a new model based on microtubules. This eventually became known as the Orch-OR theory.[11,12]

The Orch-OR theory builds upon the Objective Reduction theory by presuming that wave function collapse occurs along microtubules, and that the unique properties of the tubulin dimers that make up microtubules allow for other quantum properties which would contribute to large scale quantum activity throughout the brain.[3] As well, general anesthesia's role in rendering patients unconscious for medical procedures could be explained by its interaction with microtubules, providing a theoretical framework for the mechanism of anesthesia.[3] In short, quantum interactions along microtubules could explain consciousness.[3,14]

For much of its lifetime, Orch-OR has been considered to be a fringe theory, but recent studies have shown some support for its contentions. In a 2023 study done at Princeton University, researchers used lasers to excite tubulin dimers, causing a transfer of excitation energy across microtubules. However, the presence of anesthetics (etomidate and isoflurane) reduced this effect.[15] Further, in a 2024 study in which rats were given a drug that binds to microtubules (epothilone B) the rats took over a minute longer to fall unconscious under anesthetic than controls.[16] Both studies point to a connection between anesthesia, microtubules, and consciousness. Lastly and most remarkably, a 2024 study demonstrated a phenomenon known as superradiance occurring in large-scale tryptophan structures. Superradiance is essentially a constructive interference of quantum activity, and its presence in large structures made of tryptophan (which is present in microtubules), indicates that large-scale quantum activity can occur in biological systems at significant levels, including, perhaps, for consciousness.[17]

However, the Orch-OR theory is not without valid criticism. Many have criticized how the theory lacks explanatory power and that it is merely speculation. Other criticisms include the fact that it is unlikely that quantum fluctuations would be of sufficient magnitude or exist for sufficient time spans to have a noticeable effect on consciousness, or that in biological systems there would be an effective wave function collapse before any effect on consciousness could possibly occur, due to the chaotic environment.[18]

To conclude, the hard problem of consciousness remains one of the most difficult to crack. But although the Orch-OR theory has its flaws, its creation is a remarkable story of how different fields of science like cell biology, quantum physics, mathematics, and neuroscience can come together to create new and exciting ideas about how the mind works. And it would not exist without the keen insight and curiosity of an anesthesiologist. And as for whether or not quantum mechanics holds the key to understanding anesthesia and consciousness, it is still too early to tell, and new

...continued on page 19

...continued from page 18

discoveries only raise more questions. The experience of "going under" is still as enigmatic and mysterious as ever. But perhaps one day we will discover that the magic of anesthesia isn't just rife with secrets pertaining to the human body, but perhaps it contains the secrets of the universe itself.

References

1. Hewer CL (August 1937). "The Stages and Signs of General Anaesthesia". *British Medical Journal*. **2** (3996): 274–276. doi:10.1136/bmj.2.3996.274
2. Mashour GA (2024) Anesthesia and the neurobiology of consciousness. Neuron 112:1553–1567. https://doi.org/10.1016/j.neuron.2024.03.002
3. Hameroff S, Penrose R (2014). "Consciousness in the universe: a review of the 'Orch OR' theory". Physics of Life Reviews. 11 (1): 39–78. https://doi.org/10.1016/j.plrev.2013.08.002
4. Descartes R (1641). Meditations on First Philosophy. Paris: Michel de Soligny.
5. Libet B, Gleason CA, Wright EW, Pearl DK (1983). "Time of conscious intention to act in relation to onset of cerebral activity (readiness-potential)." Brain. 106 (3): 623–642. https://doi.org/10.1093/brain/106.3.623.
6. Mashour GA, Roelfsema P, Changeux JP, Dehaene S (2020). "Conscious Processing and the Global Neuronal Workspace Hypothesis." Neuron. 105 (5): 776–798. https://doi.org/10.1016/j.neuron.2020.01.026.
7. Albantakis L, Barbosa L, Findlay G, Grasso M, Haun AM, Marshall W, Mayner WGP, Zaeemzadeh A, Boly M, Juel BE, Sasai S, Fujii K, David I, Hendren J, Lang JP, Tononi G (2023). "Integrated information theory (IIT) 4.0: Formulating the properties of phenomenal existence in physical terms." *PLoS Computational Biology*. 19 (10): e1011465. https://doi.org/10.1371/journal.pcbi.1011465.
8. Chalmers D (1995). "Facing up to the problem of consciousness." Journal of Consciousness Studies. 2 (3): 200–219.
9. Chalmers D (2019). "Zombies and the Conceivability Argument." PhilPapers.
10. Gödel K (1931). "On formally undecidable propositions of Principia Mathematica and related systems." Monatshefte für Mathematik und Physik. 38: 173–198. https://doi.org/10.1007/BF01720607.
11. Penrose R (1989). The Emperor's New Mind: Concerning Computers, Minds and The Laws of Physics. Oxford University Press. pp. 108–109. ISBN 978-0-19-851973-7.
12. Hameroff S (n.d.). "Research Overview." Hameroff Lab. University of Arizona. https://hameroff.arizona.edu/research-overview/overview.
13. Allison R, Nunn JF (1969). "The effects of anesthetics on the central nervous system." British Journal of Anaesthesia. 41 (7): 491–498.
14. Penrose R (1989). Shadows of the Mind: A Search for the Missing Science of Consciousness. Oxford University Press. pp. 416–417, 457. ISBN 978-0-19-853978-0.
15. Kalra AP, Benny A, Travis SM, Zizzi EA, Morales-Sanchez A, Oblinsky DD, Craddock TJA, Hameroff SR, MacIver MB, Tuszyński JA, Petry S, Penrose R, Scholes GD (2023). "Electronic Energy Migration in Microtubules." ACS Central Science. 9: 352–361. https://doi.org/10.1021/acscentsci.2c01712.
16. Khan S, Huang Y, Timuçin D, Bailey S, Lee S, Lopes J, Gaunce E, Mosberger J, Zhan M, Abdelrahman B, Zeng X, Wiest MC (2024). "Microtubule-Stabilizer Epothilone B Delays Anesthetic-Induced Unconsciousness in Rats." eNeuro. 11 (8): ENEURO.0291-24.2024. https://doi.org/10.1523/ENEURO.0291-24.2024.
17. Babcock NS, Montes-Cabrera G, Oberhofer KE, Chergui M, Celardo GL, Kurian P (2024). "Ultraviolet Superradiance from Mega-Networks of Tryptophan in Biological Architectures." The Journal of Physical Chemistry B. 128 (17): 4035–4046. https://doi.org/10.1021/acs.jpcb.3c07936.
18. McKemmish LK, Reimers JR, McKenzie RH, Mark AE, Hush NS (2009). "Penrose-Hameroff orchestrated objective-reduction proposal for human consciousness is not biologically feasible." Physical Review E. 80 (2): 021912. https://doi.org/10.1103/PhysRevE.80.021912.