

Neurogenesis

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1. Core Definition

Neurogenesis refers fundamentally to the intricate biological process by which new neurons, often referred to as nerve cells, are generated within the brain. This sophisticated cellular proliferation and differentiation is a cornerstone of brain development and plasticity, ensuring the continuous replenishment and expansion of neural networks. At its heart, neurogenesis encompasses the division of progenitor cells, their subsequent differentiation into specialized neuronal subtypes, and their eventual integration into existing neural circuits. This complex sequence of events is vital for the establishment and ongoing maintenance of the central nervous system's structural and functional integrity, laying the groundwork for all higher cognitive functions and sensory processing. The precision and regulation of this process are paramount, as errors or disruptions can have profound implications for neurological health and cognitive capacity throughout an individual's lifespan.

The newly formed neurons, derived from neural stem cells or progenitor cells, undergo a series of maturation steps that include migration to their target locations, the extension of axons and dendrites to form synaptic connections, and finally, the establishment of functional communication with other neurons. This comprehensive process ensures that the brain maintains its remarkable ability to adapt, learn, and repair itself, albeit to varying degrees at different life stages. The generation of new neurons is not a simple addition of cells; rather, it is a highly orchestrated phenomenon that involves precise molecular signaling, cellular interactions, and environmental cues, all working in concert to shape the brain's architecture and function. Understanding this foundational process is central to comprehending both typical brain development and the mechanisms underlying various neurological and psychiatric disorders, offering potential avenues for therapeutic intervention.

2. Etymology and Historical Development

The term "neurogenesis" is derived from the Greek words "neuron" (nerve) and "genesis" (creation or birth), literally meaning "the birth of nerves." For a considerable period in the history of neuroscience, a prevailing dogma held that the adult mammalian brain was a static organ, incapable of generating new neurons after early development. This belief, often attributed to the influential work of Santiago Ramón y Cajal, suggested that the number of neurons was fixed shortly after birth, leading to the adage "no new neurons in the adult brain." This perspective dominated scientific thought for much of the 20th century, profoundly shaping research directions

and therapeutic approaches for neurological conditions, which largely focused on protecting existing neurons rather than fostering the growth of new ones.

However, beginning in the latter half of the 20th century, this long-held dogma began to be challenged by groundbreaking research. Pioneering studies in the 1960s by Joseph Altman and Gopal Das provided initial evidence of adult neurogenesis in rodents, specifically in the dentate gyrus of the hippocampus and the subventricular zone. These findings, though initially met with skepticism, laid the foundation for a paradigm shift in neuroscience. Subsequent research, particularly in the 1990s and early 2000s, utilizing advanced labeling techniques and genetic markers, conclusively demonstrated that neurogenesis indeed persists into adulthood in various mammalian species, including humans. This revolution in understanding opened up entirely new fields of inquiry into brain plasticity, repair, and the etiology of neurological disorders, fundamentally altering the scientific community's perception of the brain's dynamic capacity.

3. Types of Neurogenesis

Neurogenesis can broadly be categorized into two primary forms based on the developmental stage at which it occurs: embryonic/developmental neurogenesis and adult neurogenesis. Each type plays distinct yet complementary roles in establishing and maintaining the brain's functionality. The fundamental principles of cell division, migration, and differentiation underpin both processes, but their scale, location, and functional implications differ significantly, reflecting the unique demands of brain formation versus ongoing maintenance and plasticity.

3a. Embryonic/Developmental Neurogenesis

As highlighted in the original content, neurogenesis is **most active during prenatal development**, a critical period when a baby's brain is being formed. This phase, often referred to as embryonic or developmental neurogenesis, is characterized by an astonishingly rapid and prolific production of neurons that form the foundational structures of the central nervous system. During this stage, a highly specialized pool of neural stem cells residing in the ventricular and subventricular zones of the embryonic brain undergoes extensive proliferation, generating billions of neurons. These nascent neurons then embark on remarkable migratory journeys, guided by complex molecular cues, to reach their precise locations within the developing brain, forming the distinct layers and nuclei that will govern all future cognitive and physiological functions.

The sheer scale and precision of developmental neurogenesis are crucial for the proper wiring of the brain. Each newly generated neuron must not only differentiate into the correct cell type but also establish appropriate synaptic connections with thousands of other neurons, contributing to the formation of intricate neural circuits. Disruptions during this prenatal period, whether due to genetic factors, environmental toxins, or nutritional deficiencies, can have severe and often

irreversible consequences, leading to developmental disorders, cognitive impairments, and a range of neurological conditions that manifest later in life. Therefore, the robust and highly regulated nature of embryonic neurogenesis is absolutely essential for the healthy formation of a functional brain, underpinning an individual's entire neurological architecture.

3b. Adult Neurogenesis

While the peak activity of neurogenesis occurs prenatally, it is crucial to recognize that the process **continues through adulthood**. However, as the source content correctly states, new neurons are generated at a **much slower pace than during prenatal development**. In the adult mammalian brain, including humans, neurogenesis is primarily confined to two specific regions: the subgranular zone (SGZ) of the dentate gyrus within the hippocampus and the subventricular zone (SVZ) lining the lateral ventricles. The hippocampus is a brain region critically involved in learning and memory, which aligns with the belief that adult neurogenesis may be involved in these cognitive functions. The SVZ, on the other hand, primarily generates new interneurons that migrate to the olfactory bulb, playing a role in olfaction.

The newly generated neurons in the adult hippocampus must undergo a complex maturation process, including proliferation, survival, differentiation, and integration into existing neural circuits. This process is highly regulated by various intrinsic and extrinsic factors, including genetics, age, environmental enrichment, physical exercise, stress, and disease states. Unlike the massive production during development, adult neurogenesis involves a relatively small number of new neurons, yet these cells are believed to contribute significantly to brain plasticity and function. Their role in modifying existing networks and potentially enabling adaptive responses to new experiences or challenges underscores the ongoing dynamic nature of the adult brain, challenging the static view that once prevailed.

4. Key Characteristics and Mechanisms

The process of neurogenesis is characterized by several fundamental stages, each involving a precise interplay of molecular and cellular mechanisms. It begins with neural stem cells (NSCs) or neural progenitor cells (NPCs), which are multipotent cells capable of self-renewal and differentiation into various neural lineages, including neurons, astrocytes, and oligodendrocytes. These cells reside in specific neurogenic niches within the brain, such as the SGZ and SVZ in adults, where they are maintained in a quiescent or slowly dividing state until activated by appropriate signals. The proliferation phase involves the symmetric or asymmetric division of these stem cells, increasing the pool of progenitor cells that will eventually give rise to new neurons.

Following proliferation, the newly generated cells enter a phase of differentiation, where they commit to a neuronal fate. This commitment is guided by a complex cascade of transcription

factors and signaling pathways that dictate the specific subtype of neuron they will become. After differentiation, these immature neurons embark on a journey of migration, traveling along radial glial scaffolds or through tangential routes to reach their designated positions within the existing neural circuitry. Once in place, they undergo maturation, which involves extending axons and dendrites, forming synaptic connections with target neurons, and integrating functionally into the pre-existing neural network. The survival of these new neurons is not guaranteed; a significant proportion undergoes programmed cell death, or apoptosis, a process critical for refining neural circuits and eliminating cells that fail to integrate properly. This selective survival ensures that only functional and well-connected neurons persist, contributing to the overall efficiency and precision of the brain's operations.

5. Significance and Impact

The discovery and understanding of neurogenesis, particularly its persistence in adulthood, have profound implications for our comprehension of brain function and its potential for plasticity and repair. As stated in the source content, it is strongly **believed that neurogenesis may be involved in learning and memory**. This hypothesis is supported by extensive research showing that disruption of adult hippocampal neurogenesis impairs certain forms of learning and memory, while enhancement of neurogenesis can improve cognitive performance. The dynamic addition of new neurons to the hippocampus is thought to contribute to pattern separation, the ability to distinguish between similar experiences, and may play a role in the encoding of new episodic memories. This capacity for continuous neural renewal provides a substrate for the brain's lifelong ability to adapt to new information and experiences, underpinning its remarkable cognitive flexibility.

Beyond cognition, neurogenesis is also implicated in other critical brain functions, including mood regulation and responses to stress. Dysregulation of adult neurogenesis has been linked to various neurological and psychiatric disorders, such as depression, anxiety disorders, and neurodegenerative diseases like Alzheimer's disease and Parkinson's disease. For instance, reduced neurogenesis is a consistent finding in models of depression, and many antidepressant treatments have been shown to promote neurogenesis. This connection suggests that fostering new neuron growth could be a viable therapeutic strategy for improving mood and cognitive deficits associated with these conditions. Furthermore, neurogenesis holds immense promise for regenerative medicine, offering the potential to repair brain damage caused by injury (e.g., stroke) or disease by replacing lost neurons and restoring circuit function. The ability to harness and manipulate endogenous neurogenesis represents a frontier in neurotherapeutics, aiming to leverage the brain's inherent regenerative capacity to combat debilitating neurological conditions and enhance cognitive well-being.

6. Debates and Criticisms

Despite the significant advancements in understanding neurogenesis, certain aspects remain subjects of ongoing scientific debate and scrutiny, particularly regarding the extent and functional significance of adult neurogenesis in humans. While robust evidence for adult neurogenesis exists in rodents and some primates, the precise quantification and unequivocal demonstration of substantial new neuron integration in the adult human brain have been challenging. Some studies have presented compelling evidence, while others have reported minimal or no detectable neurogenesis in the adult human hippocampus beyond early development, leading to a vigorous scientific discourse. These discrepancies often stem from variations in methodology, including post-mortem tissue analysis, detection markers, and the inherent difficulties in studying dynamic cellular processes in living human brains. The debate underscores the complexity of extrapolating findings from animal models directly to humans and highlights the need for more refined and robust techniques to unequivocally resolve the issue.

Furthermore, even where adult neurogenesis is confirmed, its functional relevance and specific contributions to behavior and cognition are still being elucidated. While correlations between neurogenesis levels and cognitive performance or mood exist, establishing definitive causal links and understanding the precise mechanisms by which a relatively small number of new neurons can exert significant effects on complex brain functions remains a challenge. Critics also point to the ethical considerations surrounding potential therapeutic interventions aimed at enhancing neurogenesis, particularly concerns about uncontrolled cell proliferation and potential off-target effects. The precise control over cell fate, migration, and integration is paramount for any clinical application, and unintended consequences, such as tumor formation or aberrant circuit wiring, must be rigorously addressed. These ongoing debates are crucial for advancing the field, driving the development of more precise research tools, and fostering a deeper, more nuanced understanding of neurogenesis in health and disease.

Further Reading

[Neurogenesis - Wikipedia](#)

[Adult Neurogenesis - Wikipedia](#)

[Hippocampus - Wikipedia](#)

[Learning - Wikipedia](#)

[Memory - Wikipedia](#)