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Comparative cytoarchitecture of the torus semicircularis in the catfish *Clarias batrachus*

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Abstract
The Torus semicircularis (TS) in catfish is a pivotal midbrain integration center, involved in processing sensory inputs from the auditory, visual, and lateral line systems. This study explores the cytoarchitecture of the TS in *Clarias batrachus*, a species with weak electroreception. The analysis reveals a layered structure consisting of two nuclei, the nucleus lateralis and nucleus centralis, with predominant bipolar neurons. When compared to the strongly electroreceptive Ictalurus punctatus, which has more multipolar neurons, these findings suggest evolutionary adaptations in sensory processing mechanisms. The study contributes to the understanding of the neural architecture that underlies sensory integration in different aquatic environments.

Keywords: Torus semicircularis, *Clarias batrachus*, cytoarchitecture, sensory processing, electroreception

Introduction
The Torus semicircularis (TS) serves as a central mesencephalic hub for integrating sensory information in teleost fish. Previous research has highlighted the complexity of the TS in processing inputs from auditory, visual, and lateral line systems, which are crucial for survival in aquatic environments (Knudsen, 1977) [5]. While extensive studies have been conducted on the TS of various species, including strongly electroreceptive fishes, there is limited information on the cytoarchitecture of the TS in weakly electroreceptive species such as *Clarias batrachus*.

This study aims to fill this gap by examining the neuronal types and organization of the TS in *C. batrachus*, comparing it with the TS of Ictalurus punctatus a species known for its strong electroreception. By investigating the differences in neuronal composition, this study seeks to shed light on how sensory processing adaptations correlate with ecological niches and electroreception abilities.

Materials and Methods
Animal Preparation
Adult specimens of *Clarias batrachus* were anesthetized using a solution of methyl-sulphonate-ethyl-m-aminobenzoate (MS-222 Sandoz) to minimize stress. Brains were extracted and immediately fixed in a 2% paraformaldehyde solution to preserve neural structures for histological examination.

Neuronal Staining and Analysis
Neuronal structures were stained using the Golgi-Colonnier method, which is effective for visualizing the intricate morphology of individual neurons. Measurements of neuronal cell sizes were conducted using a Zeiss ocular micrometer. Camera lucida was employed to create detailed drawings of the Golgi-impregnated neurons. To assess the overall cytoarchitecture, Nissl staining was performed to reveal the layering within the TS.

Results
Structural Organization of the Torus Semicircularis
The Torus semicircularis of *Clarias batrachus* is composed of two distinct nuclei: the nucleus lateralis and nucleus centralis. Both nuclei exhibit a well-defined layered architecture, characterized by alternating cell-rich and cell-poor laminae. The structural organization is indicative of the TS's role in the integration of complex sensory information.

In the torus semicircularis (TS) of *Clarias batrachus*, a catfish species, researchers have identified a diverse array of neuronal types, each contributing uniquely to the brain's sensory processing capabilities. The three primary types of neurons include unipolar, bipolar, and multipolar neurons.

Neuronal Typology

Unipolar neurons are relatively simple in structure, characterized by having a single projection that branches into both a dendrite and an axon. These neurons are found in moderate numbers within the TS and are thought to be involved in basic signal transmission, possibly relaying information from sensory receptors to other parts of the brain for further processing.

Bipolar neurons are the most prevalent neuronal type in the TS of *C. batrachus*. These neurons possess two distinct processes: one axon and one dendrite, which extend from opposite ends of the cell body. Their abundance suggests a critical role in the processing and relay of sensory inputs, particularly in interpreting the environmental signals that the fish receives. Given their prominence, bipolar neurons likely play a central role in the integration of sensory information, ensuring that the fish can respond appropriately to its surroundings.

Multipolar neurons, on the other hand, are less common in the TS of *C. batrachus* compared to bipolar neurons. These neurons have multiple dendrites and a single axon, allowing for the integration of a large amount of information from various sources. The relative scarcity of multipolar neurons may reflect a distinct organizational strategy in *C. batrachus*, particularly when compared to species that rely heavily on electroreception for navigation and hunting. In strongly electroreceptive species, multipolar neurons might be more abundant to process the complex signals associated with electroreception.

Additionally, pyramidal neurons were observed, albeit in smaller numbers, contributing to the overall diversity of the neuronal population in the TS. Pyramidal neurons, known for their characteristic pyramid-shaped cell bodies and long, branching dendrites, are typically involved in higher-order processing functions, such as integrating sensory inputs and coordinating motor outputs. Their presence, even in limited numbers, suggests that the TS of *C. batrachus* may have some capacity for more complex processing and integration of sensory information, beyond basic signal transmission.

This diversity of neuronal types within the TS highlights the complexity of sensory processing in *C. batrachus*, a species that, while not as strongly electroreceptive as others, still relies on a finely tuned neural system to navigate its environment and respond to sensory stimuli.

Discussion

The predominance of bipolar neurons in the TS of *Clarias batrachus* contrasts sharply with the neuronal composition in Ictalurus punctatus, where multipolar neurons dominate. This difference likely reflects the distinct sensory processing needs of these species, driven by their respective electroreception capabilities. In I. punctatus, strong electroreception necessitates a more complex network of multipolar neurons for processing electric fields, which is less critical for the weakly electroreceptive *C. batrachus*.

The layered structure of the TS in *C. batrachus*, with alternating cell-rich and cell-poor layers, suggests a specialized mechanism for sensory integration. This laminar organization is consistent with findings in other teleosts, where parallel processing of sensory information is crucial for adaptive behavior (Carr et al., 1981; Sas & Maler, 1983) [4, 6].

Conclusion

This study provides a detailed examination of the cytoarchitecture and neuronal composition of the Torus semicircularis in *Clarias batrachus*. The findings reveal significant differences in the TS structure and neuron types when compared to strongly electroreceptive species, highlighting the role of evolutionary adaptation in shaping sensory processing systems. Future research should explore the functional implications of these structural differences, particularly in the context of environmental and behavioral adaptations.

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