

Cell bodies in a cage

A new 'cell theory' is needed to explain complex intercellular connections.

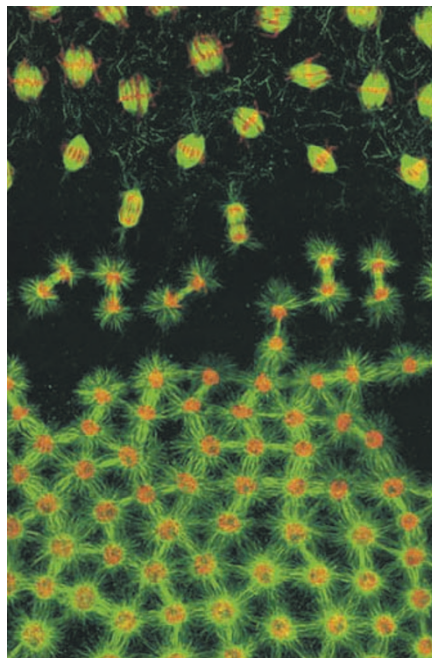
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The concept of the cell as the fundamental structural and functional unit of a multicellular organism stems from the observations of Robert Hooke in 1665 and Nehemiah Grew in 1682, both of whom reported on the 'cells' of plant tissues. It was 150 years before the universal 'German cell theory' — as it was originally known — was proposed by Theodore Schwann and Matthias Schleiden, but even this was not widely accepted for another 100 years. Brain tissues, with their large neurons interconnected by very long thin processes known as axons, had represented a particular hurdle for the early cytologists. But after the cellular basis of neurons and brain tissue had been accepted following the work of Ramón y Cajal and Camillo Golgi, cell theory spread rapidly as a rather dogmatic doctrine.

Plants have been notable and important tools in this process of cellular discovery. Not only did they allow the identification of the actual cells, but they also enabled the discovery of nuclei, plasma membrane, microtubules, mitosis and the cell-division cycle. Paradoxically, recent advances in plant cell biology challenge the dominant position of the current version of cell theory.

Cell theory identifies the cell as the elementary unit from which all living organisms are constructed. Although this holds true for all prokaryotic and unicellular eukaryotic organisms, the supracellular structure of higher plants presents a problem. Cell-to-cell channels, called plasmodesmata, connect each plant cell to its neighbours, facilitating the exchange of large molecules (proteins and RNAs) and allowing the mass flow of smaller molecules. Thus, in contradiction with the cell theory, plant cells are neither physically separated nor structurally independent. The challenge to the cell theory does not stop with plants. There are numerous examples of supracellular assemblages known as coenocytes (which are formed by mitosis with the absence of subsequent cell division) and syncytia (which are formed by cells fusing together), both of which are found throughout the eukaryotic superkingdom. These giant cells contain multiple nuclei.

In 1853, Thomas Henry Huxley noted a similar inconsistency between the structure of some tissues and the German cell theory of his day. Huxley was convinced that cells of multicellular organisms are not anatomically isolated. Accordingly, he could not accept that cells were the elementary units of living



Are nuclei and their surrounding microtubules the fundamental unit of supracellular structures?

organisms. Huxley's conceptual problem with cell theory is still relevant, because supracellularity is nowadays an accepted feature of higher plants. Moreover, this identity crisis of the 'cell' is not simply a problem confined to plants, as nanotubular intercellular bridges are also generated *de novo* between animal cells. These cell-to-cell connections can create complex networks of cytoplasmic continuity that facilitate cell–cell transport, of, for example, endosomal-like vesicles. It seems that algae, fungi, plants and animals have all independently developed both supracellularity and multicellularity.

To harmonize all these diverse cytological observations of eukaryotic forms, a discrete subcellular element is required that will take over from the cell as the fundamental unit, not only of eukaryotic structure, but as a propagule of life itself. One possible candidate is the 'cell body' which was proposed for animal cells by the late Daniel Mazia in 1993. The 'cell body' comprises the nucleus and a set of perinuclear radiating microtubules, and can be regarded as the basic unit of eukaryotic life, being both autonomous and self-reproducing.

The 'cell body' concept is particularly suitable for supracellular plants. Plant nuclei make use of the whole of their nuclear surface to organize radiating microtubules. This feature is prominent in multinuclear coenocytes and syncytia found throughout the eukaryotic superkingdom, where the

radiating microtubules determine the regular spacing of individual nuclei ('cell bodies'). Importantly, 'cell body' microtubules radiate from the organizing sites near or at the nuclear surface into the cytoplasm. This extranuclear scaffold structure provides the structural basis for the well known (but little understood) observation that the volume of the nucleus has a fixed relationship to the size of the cell (the cytonuclear ratio), a principle that underlies the organization of every eukaryotic cell.

The origin of the 'cell body' attracts further speculation. Its dual nature (nucleus and microtubules) may be the result of serial and progressive endosymbiotic events that took place during the early evolution of the eukaryotic cell. In fact, the eukaryotic cell itself is supracellular as it has been developed by the merger of several originally free-living cells. After long discussions, the endosymbiotic origin of mitochondria and plastids is now widely accepted.

Whereas 'cell bodies' cannot arise *de novo*, and are formed only by a structural splitting of pre-existing 'cell bodies' during the highly conserved process of mitosis, the plasma membrane, along with its associated structures and assemblies, can be formed *de novo* through secretory and synthetic activities organized by the 'cell body'. In plants this occurs every time a cell divides at cytokinesis! In addition, the 'cell body' is inherently motile, but is confined within the boundary structure of the plasma membrane with its associated actin cytoskeleton. The active exploration of cytoplasmic space by the 'cell bodies' is a feature that makes them appear akin to active, living organisms trapped within a protective cellular 'cage'; this exploration also underlies the cytonuclear ratio. Altogether, the 'cell body' concept represents a satisfactory and coherent conceptual framework for understanding both supracellularity and cellularity throughout the eukaryotic superkingdom. ■

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FURTHER READING

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