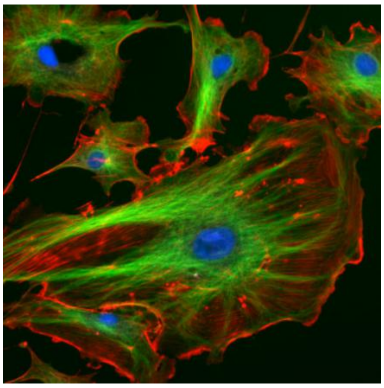
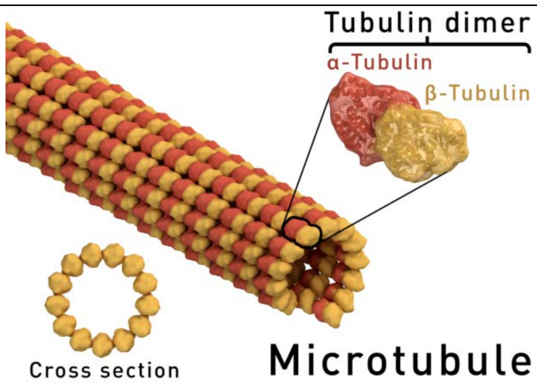
生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	微管動態地改變長度 (Microtubules dynamically change length)
生物系統 LIVING SYSTEM	真核生物 (Eukaryotes)
功能類別 FUNCTIONS	#改變位置 #改變大小/形狀/質量/體積 #在液體中/上移動 #在固體中/上移動 #物理性組成結構 #調節細胞代謝過程 #調節生殖或生長 #Modify position #Modify size/shape/mass/volume #Move in/on liquids #Move in/on solids #Physically assemble structures #Regulate cellular process #Regulate reproduction or growth
作用機制標題	細胞內微管透過組合及解離的效率變化迅速改變長度 (Microtubules in cells quickly change length by altering the rate of assembly and disassembly)
生物系統/作用機制示意圖	 

作用機制摘要說明 (SUMMARY OF FUNCTIONING MECHANISMS)

真核細胞是由許多微管所組成，細胞通常被想像成一個裝著水或化學物的鬆散液囊，但其實是由各種結構及胞器密集組合而成，所有部分都持續地進行著重要的功能。這些功能很多都由被動式擴散的訊號粒子所調控，也有一些需要主動運輸。微管構成了細胞物理性骨架，使它們能移動及改變外形，而且也構成了一部分細胞組成分運輸的基礎建設。微管亦會運送染色體，所以是細胞分裂及複製的重要一部分。

微管由大量的微管蛋白所組成，細胞質中鬆散的微管蛋白與鳥苷-5'-三磷酸 (GTP) 粒子結合並活化，在這個活化態中的微管蛋白會依附在生長中微管的一端，但是微管會分解（水解）GTP 成為二磷酸鳥苷 (GDP)，與 GDP 結合的微管蛋白比較傾向從微管分離。這個反應不會即時出現，而是在微管蛋白與 GTP 結合到水解成 GDP 之間會有延遲。因為結合 GDP 的微管蛋白不能從微管已經形成的一端彈走，只能從另一端解離。新的微管蛋白的結合效率會比水解的效率更高，所以會形成一個 GTP 及微管蛋白結合體組成的帽子，防止微管破碎。但是如果微管蛋白的新增速率慢下來，以及末端的蛋白把 GTP 水解成 GDP，保護帽就會消失而微管亦會開始崩解。這種微管從生長到萎縮的突然轉換稱為微管的「大災難」，也是調控微管長度的一個重要部分。只要 GTP 及微管蛋白結合體重新組

成，微管就會重新生長，稱為「拯救」。

調控微管大災難的精確機制尚未明瞭，但我們已經知道它們會被多重因子所調控。大災難在較長的微管中比較常出現，顯示有一個多步驟的作用去保護較短微管，避免出現多次大災難，促使其生長。

Eukaryotic cells are packed full of microtubules. Far from being a loose sac of water and chemicals, as they are often envisaged, cells are actually densely packed with structures and organelles, all constantly carrying out crucial functions. While a lot of these functions are regulated by the passive diffusion of signaling molecules, many of them require active transport. Microtubules make up the physical skeleton of cells, enabling them to move and change shape, and they also form part of the infrastructure along which cellular components are transported. Microtubules also transport chromosomes, and so are critical for cell division and replication.

Microtubules are formed from numerous copies of the protein tubulin. Loose tubulin in the cytoplasm binds to molecules of GTP and becomes activated. In its active form, individual tubulin proteins will attach to one end of a growing microtubule. However, tubulin breaks down (hydrolyzes) GTP to GDP and GDP-bound tubulin is much more likely to dissociate from a microtubule. This reaction does not occur immediately, and there is a delay between tubulin becoming bound to GTP and its hydrolyzation to GDP. Because GDP-bound tubulin cannot pop out of the side of a microtubule in which it is already incorporated and only dissociates from one end, as long as new tubulin is being added to the end of a microtubule at a faster rate than hydrolyzation is occurring, there will be a cap of GTP-bound tubulin that will prevent the microtubule falling apart. However, if the rate of new tubulin addition slows and the protein at the tip hydrolyzes its GTP to GDP, this protective cap is lost and the microtubule will begin to fray. This sudden switch from growing to shrinking is called a microtubule "catastrophe" and is an important part of regulating tube length. Once a cap of GTP-bound tubulin reforms, the microtubule begins to grow again, termed "rescue".

The precise mechanisms regulating microtubule catastrophe are not yet known, although it is understood to be regulated by multiple different factors. Catastrophe occurs at a higher rate in longer microtubules, indicating there must be a multi-step process that protects shorter microtubules from undergoing frequent catastrophe and enables them to grow.

文獻引用 (REFERENCES)

「微管在細胞功能中扮演著重要角色，與肌動蛋白絲與中間絲構成了真核細胞的細胞骨架，這群聚合物共同負責大部分的細胞結構及空間配置。微管亦參與運輸、移動及重新配置，還有無數的動態活動，包括了馬達蛋白如驅動蛋白及動力蛋白的活動、纖毛及鞭毛的擺動，以及細胞分裂時染色體的分離。」(Sept 2007: R764)

「微管個體末端的動態行為稱為「動態不穩定」，這種行為顯示了微管反覆的週期性生長，是由於偶爾切換成急速萎縮（稱為微管「大災難」），再從萎縮切換回生長（稱為微管『拯救』）。」(Gardner et al. 2013: 14)

「微管的『大災難』事件是指突然從生長中狀態轉換成急速變短的狀態，被廣為接受的說法是它牽涉到一個隨機的單獨事件，例如末端保護構造的突然消失 [1-3]，這個單步驟的機制顯示微管在同一時間點下會有著相同的機率發生大災難，與微管的生長長度不相關…但是，微管在體內跟體外長度及年齡分佈的測量並沒有呈現一個簡單的指數衰變 [4–13]。雖然較長微管的長度分佈會呈現指數衰變，但在較短微管中沒有出現預期的指數分佈…這個幼年微管會有較少機率出現大災難的發現，顯示微管會老化：大災難頻率並不是一個常數，而是會隨著時間增加。」(Gardner et al. 2013: 14)

“Microtubules are essential players in the function of the cell. Together with actin filaments and intermediate filaments, they comprise the cytoskeleton in eukaryotic cells, and this group of polymers is collectively responsible for providing most of the structure and spatial organization in the cell. Microtubules are also involved in transport, migration and reorganization and have numerous dynamic roles, including movement via motor proteins such as kinesin and dynein, the beating of cilia and flagella, and the segregation and separation of chromosomes during cell division” (Sept 2007: R764)

“The dynamic behavior at the end of an individual microtubule is termed ‘dynamic instability’. This behavior manifests itself by periods of persistent microtubule growth interrupted by occasional switching to rapid shrinkage (called microtubule ‘catastrophe’), and then by switching back from shrinkage to growth (called microtubule ‘rescue’)” (Gardner et al. 2013:14)

“A microtubule ‘catastrophe’ event manifests itself by the sudden switch of a growing microtubule into a rapidly shortening state. The widely accepted view of microtubule catastrophe is that it involves a single random event, such as the sudden loss of a protective end structure [1 – 3]. This single-step mechanism implies that a microtubule has the same probability of undergoing catastrophe at any given point in time, irrespective of how long it has been growing already...However, measurements of microtubule length and lifetime distributions both in vitro and in vivo do not display a simple exponential decay [4 – 13]. Although the distribution of microtubule lengths appears to decay exponentially at longer lengths, the predicted exponential distribution is not observed at shorter lengths...The finding that young microtubules are less probable to undergo catastrophe means that microtubules age: catastrophe frequency is not a constant, but rather increases with time.” (Gardner et al. 2013: 14)

參考文獻清單與連結 (REFERENCE LIST)

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Schek, H. T., M. K. Gardner, J. Cheng, D. J. Odde, and A. J. Hunt. (2007). Microtubule assembly dynamics at the nanoscale. *Current Biology* 17: 1445-1455. (https://doi.org/10.1016/j.cub.2007.07.011)

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延伸閱讀
生物系統延伸資訊連結 (LEARN MORE ABOUT THE LIVING SYSTEM/S)
https://en.wikipedia.org/wiki/Eukaryote
撰寫/翻譯/編修者與日期
譚國鋈翻譯 (2020/04/06)；許秋容編修 (2020/11/25)；紀凱容編修 (2020/11/25)
AskNature 原文連結
https://asknature.org/strategy/microtubules-dynamically-change-length/