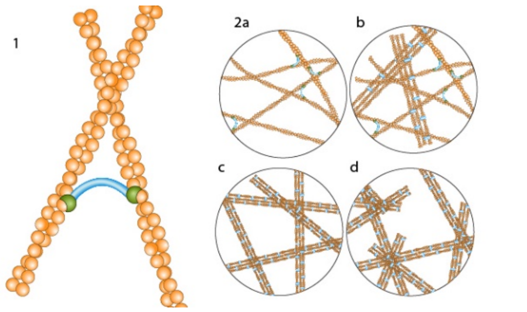
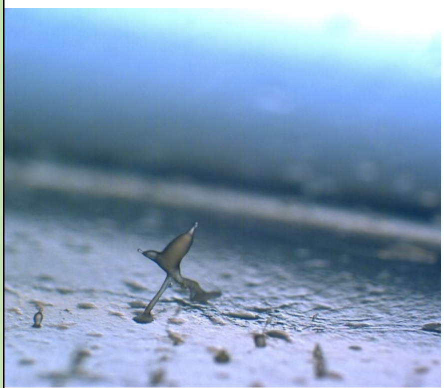
生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	微觀「骨架」支持細胞結構和運動 (Microcopic "skeletons" support cellular structure and movement)
生物系統 LIVING SYSTEM	盤基網柄菌 *Dictyostelium discoideum*
功能類別 FUNCTIONS	#化學性組成聚合物 #改變材料特性 #調節細胞代謝過程 #Chemically assemble polymers #Modify material characteristics #Regulate cellular processes
作用機制標題	變形體的細胞骨架透過對環境改變環境線索的反應而改變肌動蛋白聚合物絲的交叉鏈結，從而迅速改變特性 (Cytoskeletons of an amoeba change properties quickly by varying cross-links of actin polymer filaments in response to changing environmental cues.)

生物系統/作用機制示意圖





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

想像一下，如果我們的骨骼結構可能會因應即時情況而發生變化—支撐重物時骨骼變厚並固化，或者在慢跑時骨骼變得更輕盈和更有彈性。儘管我們不能做到這一點，但單細胞生物如變形體等卻可以。肌動蛋白聚合物細絲 (actin polymer filament) 是細胞骨架的基礎，它們以不同的方式相互交叉鏈結形成各種網絡架構。該系統的關鍵是將肌動蛋白絲交叉鏈結在一起的「肌動蛋白結合蛋白」(ABP, actin binding protein)。變形體之一的盤基網柄菌 *Dictyostelium discoideum* 使用肌動蛋白絲和 ABPs 形成具不同形狀和特性的結構材料，以實現多種功能，例如：運動、營養物質的內部運輸和繁殖。為了發揮這些不同的功能，肌動蛋白纖維網絡需要快速並反覆地分解和重造。控制這些變化的一種方法是改變 pH 值。盤基網柄菌的 ABPs 有高含量的氨基酸組氨酸，這使得肌動蛋白纖維

網絡易於透過調節 pH 來進行結構調控。影響 ABP 位置和濃度的條件，可使細胞在短時間改變其細胞骨架形狀和特性。

Imagine if our skeletal structure could change in response to immediate circumstance--bones thicken and solidify when supporting heavy loads or become lighter, more airy and springy when jogging. While we can't do that, single-celled organisms such as amoeba can. Actin polymer filaments, the basis of cellular skeletons (cytoskeleton), cross-link to each other in different ways to form a variety of network architectures. Key players in this system are "actin binding proteins" (ABP) that cross-link actin filaments together. The amoeba, *Dictyostelium discoideum*, uses actin filament and ABPs to form structural materials with different shapes and properties for diverse functions such as locomotion, internal transport of nutrients, and reproduction. To play these various functional roles, actin fiber networks need to be quickly and repeatedly broken down and reformed. One way to control these changes is by varying pH levels. *D. discoideum*'s ABPs contain a high content of the amino acid, histidine, which makes the actin fiber networks susceptible to structural regulation by pH adjustment. The adjustment conditions that effect ABP positioning and concentration allow for the cell to change its cytoskeletal shape and properties in relatively short order.

文獻引用 (REFERENCES)

「肌動蛋白骨架是一種蛋白質形成的網狀聚合物，負責維持細胞的機械穩定性。這種生物聚合物網絡，對細胞的空間結構與階段變化是非常重要的，例如細胞移動、分裂和細胞內運輸。細胞骨架因此需要快速和有效的再組織化和重組，進而提供細胞完整的結構和力學穩定性。細胞透過使用蛋白質連接絲狀肌動蛋白 (F-actin)，並建構複雜的網狀結構來應對這項挑戰。交叉鏈接蛋白的分子特性很大程度上取決於細胞的（微觀）結構、黏彈性和網狀結構的力學…細胞可利用肌動蛋白結合蛋白，去建構具有特定形態和力學性質的動態絲狀肌動蛋白組裝體。」(Lieleg 2010: 218)

「ABP 誘導 F-肌動蛋白組裝體的兩種常見類型：單個交叉鏈接的肌動蛋白絲和肌動蛋白束的網狀結構。在細胞骨架的特定區域中，通常會以其中一種組裝體作為主要的類型，或者它們可以共同存在，形成相當複雜的複合相。」(Lieleg et al. 2010: 219）

「較小的交叉鏈接蛋白…傾向於將肌動蛋白絲緊密地包裝成平行束。而較大的交叉鏈接分子則…傾向於引起更複雜相的行為：在低濃度下，它們將肌動蛋白絲交聯成網絡或凝膠；而在較高濃度下，則形成完全的束狀或不同幾何形狀的複合網狀結構。」(Lieleg et al. 2010: 220）

「交叉鏈接蛋白的結合親和力通常也對特定的化學刺激敏感，這種刺激可使在不同的網狀體間有切換的可能…盤基網柄菌 hisactophilin 蛋白的高組氨酸含量導致該蛋白與 F-肌動蛋白的結合對 pH 敏感…ABP 濃度的增加不僅改變了 F-肌動蛋白網絡的結構，也可以將其彈性反應提高多達 1000 倍。」(Lieleg et al. 2010: 221）

「不同於柔韌性聚合物，半柔韌性生物聚合物如 F-肌動蛋白具非均向性 (anisotropy)，其主要輪廓對垂直（彎曲）或平行施加（拉伸/擠壓）的壓力能表現出不同的反應。」(Lieleg et al. 2010: 222)

"The actin cytoskeleton, a network of protein-polymers, is responsible for the mechanical stability of cells. This biopolymer network is also crucial for processes that require spatial and temporal variations in the network structure such as cell migration, division and intracellular transport. The cytoskeleton therefore has to combine structural integrity and mechanical stability with the possibility of fast and efficient network reorganization and restructuring. Cells meet this challenge by using proteins to link filamentous actin (F-actin) and construct complex networks. The molecular properties of the cross- linking proteins determine to a large extent the (micro)structure, viscoelastic properties and dynamics of the resulting networks…To construct dynamic F-actin assemblies with specific morphologies and mechanical properties cells make use of actin binding proteins (ABPs)." (Lieleg 2010: 218)

"Two generic types of ABP-induced F-actin assemblies: networks of individual cross-linked actin filaments and actin bundles. In particular regions of the cytoskeleton either one of these assembly types may dominate or they may coexist forming a rather complicated composite phase." (Lieleg et al. 2010: 219)

"Small cross-linking proteins…tend to tightly pack actin filaments into parallel bundles. Larger cross-linking molecules…tend to induce a more complex phase behavior: while at low concentrations they cross-link actin filaments into networks or gels, at higher concentrations purely bundled phases or composite networks with a rather diverse geometry occur." (Lieleg et al. 2010: 220)

"The binding affinity of cross-linking proteins is often also sensitive to specific chemical stimuli. Such stimuli may make it possible to switch between different network architectures…The high histidine content of *Dictyostelium discoideum* hisactophilin causes the binding of this protein to F-actin to be pH sensitive…An increase in ABP concentration not only alters the structure of an F-actin network but can also enhance its elastic response up to 1000 fold." (Lieleg et al. 2010: 221)

"[I]n contrast to flexible polymers—semi-flexible biopolymers such as F-actin are anisotropic and show a different response to forces perpendicular (bending) or parallel (stretching/compression) to the mean contour." (Lieleg et al. 2010: 222)

參考文獻清單與連結 (REFERENCE LIST)

Lieleg, O., M. M. A. E. Claessens, and A. R. Bausch. (2010). Structure and dynamics of cross-linked actin networks. *Soft matter* 6: 218-225. (https://doi.org/10.1039/b912163n)
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生物系統延伸資訊連結 (LEARN MORE ABOUT THE LIVING SYSTEM/S)
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