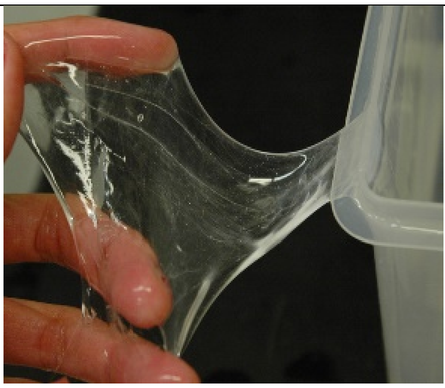
生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	黏液迅速膨脹並產生保護 (Slime rapidly expands and protects)
生物系統 LIVING SYSTEM	盲鰻 Myxini (Hagfish)
功能類別 FUNCTIONS	#獲取、吸收、或過濾液體 #改變大小/形狀/質量/體積 #形狀/材料最佳化 #保護免受動物危害 #Capture, absorb, or filter liquids #Modify size/shape/mass/volume #Optimize shape/materials #Protect from animals
作用機制標題	海洋底棲生物盲鰻受到威脅時會向周圍海水釋放大量黏液 (Hagfishes are marine, bottom-dwelling fishes that release large amounts of slime into the surrounding water when disturbed.)
生物系統/作用機制示意圖	

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

盲鰻是一種海洋底棲魚類，牠們在受到威脅時會向周圍海水釋放大量的黏液。這種大量的黏液之成分包括黏蛋白（mucin，一種具有高保水力的蛋白質）、長蛋白質絲和海水，此兩種相互作用的物質可暫時性的圍繞住盲鰻。

黏液的形成從盲鰻體側的腺體開始，沿著體側可以看到黏液腺體的開口有如小孔洞。蛋白質絲最初盤繞在腺絲細胞 (gland thread cell)，就像一團綑好的毛線；而黏蛋白則是保存在腺體黏液細胞 (gland mucous cell) 的囊泡中（膜包圍的囊狀結構）。每個黏液腺體中都會有這兩種細胞，並被肌肉所包圍著。當盲鰻收縮腺體肌肉時，絲線細胞和黏液細胞有如濃縮的混合物，通過腺管被擠出。推擠出至黏腺開口的物質與海水活躍的混合，引起細胞破裂並釋放出內容物至海水中。成束的蛋白質絲散開來，囊泡破裂釋放出黏蛋白與之結合，此網狀結構迅速擴張成大量的稀釋黏液，像細篩一樣暫時保存水分。

研究人員相信黏液能作為對抗有腮掠食者的防禦對策，能以纖維狀黏液堵塞腮部。觀看此水底下的影片展示盲鰻如何在遇到掠食者時以黏液逃脫。

Hagfishes are marine, bottom-dwelling fishes that release large amounts of slime into the surrounding water when disturbed. The mass of slime consists of mucins (a type of protein with high water-holding capacity), long protein threads, and the seawater that these two interacting components temporarily trap amongst them.

The formation of this slime starts in glands lining the hagfish body, along which slime gland openings are visible as pores. Protein threads are initially tightly coiled into gland thread cells, resembling skeins of yarn, while mucins are held within vesicles (membrane-bound sacs) in gland mucous cells. Both types of cells are packed into each slime gland, which is surrounded by muscles. When the hagfish contracts these gland muscles, the thread cells and mucous cells are pushed out as a concentrated mixture through the gland duct. Travelling through the duct and actively mixing with seawater outside the gland opening cause the cells to burst and release their packaged contents into the water. The bundled protein threads unravel and the mucins from ruptured vesicles attach to them, and this network rapidly expands into a large, dilute mass of slime that temporarily holds water like a fine sieve.

Researchers believe that the slime functions as a defense against predators with gills, which can become clogged with the fibrous slime. Check out this underwater video footage demonstrating that hagfish can slime their way out of a predatory encounter.

文獻引用 (REFERENCES)

「盲鰻最為人熟知的就是在緊張時會產生大量的黏液。牠們的黏液被認為是對抗以腮呼吸掠食者的防禦機制，被發現能減少水分流過魚類的腮部。盲鰻黏液由兩種相互作用的物質所組成，黏液絲束及黏液囊泡，兩種物質皆會從盲鰻的腹外側 (ventrolateral) 釋放出。每個黏液腺體被橫紋肌及結締組織囊泡所包圍，其中包含大量的腺絲細胞及腺體黏液細胞。腺絲細胞含有緊密綑綁成束、富含中間纖維的聚合物，而腺體黏液細胞則產生含有黏蛋白（一類醣蛋白）的囊泡。兩種細胞皆會在通過黏液腺管時部分破裂，造成原生質膜的流失，釋放出絲束及黏蛋白囊泡到外界環境。黏蛋白囊泡透過全分泌腺 (holocrine secretion) 釋放，而不是透過黏液細胞膜與囊泡融合後以胞吐作用 (Exocytosis) 釋放黏液顆粒的典型黏液分泌機制。在這種方法下的黏液囊泡能保持完整，直至與外界環境中的海水接觸。」

「當盲鰻釋放的分泌液與對流的海水接觸混合後便會形成成熟的黏液。在混合時的攪動造成絲束拆解成 10-17 公分的長度，提供了巨大的表面積給從破裂囊泡中釋放的黏液附著。完全形成的黏液是一個複雜的網絡，黏液絲線及破裂的黏蛋白可以像一個細密的篩網般以管道形式包圍海水。絲束及破裂的黏蛋白之相互作用在成熟黏液的生產中是關鍵的。」(Herr et al. 2010: 1092; in-line citations removed from quote)

「當被騷擾時，大西洋盲鰻產生大量從黏液腺體分泌的黏液，由水合蛋白絲束及膜結合黏蛋白囊泡所組成。當這些分泌液與海水接觸時，絲束拆解開及黏蛋白囊泡膨脹破

裂。囊泡在海水中破裂及在腺體中維持穩定的機制尚未明瞭，雖然相信囊泡膜對除了多價陰離子以外的大部分離子具有通透性。我們的假說是黏液腺體分泌液中最豐富的化合物對黏蛋白囊泡有穩定作用。為了驗證此假說，我們研究了盲鰻黏液分泌中液體組成分的化學組成，並檢驗這些溶質的功能來測試其保持囊泡在壓縮狀態的能力。我們發現原生質中的鉀離子濃度十分高，而鈉、氯及鈣離子濃度則相當低。我們的分析則證實了有高濃度的甲胺，例如氧化三甲胺 (TMAO)、甜菜鹼及二甲基甘氨酸，在腺體液中總濃度為 388 mmol l^{-1}。體外破裂檢驗展示了 TMAO 及甜菜鹼對破裂皆有顯著效果，但都不能完全阻止黏蛋白膨脹及破裂，即使是在高濃度下。這顯示了某些其它的機制如腺絲細胞中的化學微環境，或是流體壓力維持了腺體中囊泡的穩定性。」(Herr et al. 2010: 1092)

「…[盲鰻]黏液源自兩種腺體分泌液，包括束狀的細胞骨架中間纖維（絲束）及黏蛋白囊泡…絲束的展開涉及到從 150 µm 長度的橢球狀線綑在一瞬間拆解成一根 100 倍長的絲線。我們的假說是絲束的展開需要劇烈的流體動力攪動以及黏蛋白囊泡的存在，這些在整體黏液展開中皆為必要的。在這裡我們提供了證據證明攪動及黏蛋白囊泡對於絲束的解開非常關鍵。」(Winegard & Fudge 2010: 1235)

「我們部署的影片證實了盲鰻使用黏液分泌作有效對抗掠食者的防禦機制之假說。我們獲得的連續鏡頭顯示了黏液能影響依靠腮部呼吸的掠食者，透過增加水流的阻力來堵塞牠們的腮部。」(Zintzen et al. 2011: 2)

「掠食者對盲鰻皮膚的直接刺激似乎是觸發黏液分泌的原因。當潛在的掠食者接近盲鰻時並沒有觀察到主動的黏液分泌行為，但只有在掠食者嘗試啃咬或吞食盲鰻時才會開始分泌。在連續鏡頭中觀察到的腺體的局部性控制及協調，在實驗室研究中被證實，並有非常高的逃脫效率。這種快捷行為亦足以避免盲鰻受到任何傷害。(Zintzen et al. 2011: 3)

“Hagfishes are known for producing large volumes of slime when stressed. Their slime is believed to act as a defense mechanism against gill-breathing predators, as it has been shown to reduce water flow over the gills of fish. Hagfish slime is composed of two interacting components, slime thread skeins and mucin vesicles, which are both released from glands along the ventrolateral length of the animal. Each slime gland is surrounded by striated muscle and a connective tissue capsule, and contains large numbers of gland thread cells and gland mucous cells. Gland thread cells contain skeins of tightly coiled polymers rich in intermediate filaments, while gland mucous cells produce vesicles containing mucins, a class of glycoproteins. Both cell types rupture partially as they pass through the slime gland duct, causing each to lose its plasma membrane, and releasing both thread skeins and mucin vesicles into the external environment. The mucin vesicles are released by holocrine secretion rather than the more typical mechanism of mucus secretion through fusion of vesicles with the membrane of the mucous cell and release of mucin granules by exocytosis. In this way, the mucin vesicles remain intact until they come into contact with seawater in the external environment.”

“The mature slime is formed when exudate released from the hagfish contacts convectively mixing seawater. Agitation during mixing causes the thread skeins to uncoil to lengths of 10–17 cm, providing a large surface area to which the mucins released from the ruptured vesicles can attach. The fully formed slime is a complex network capable of confining seawater to channels between the slime threads and ruptured mucins like a fine sieve. The interaction between the thread skeins and ruptured mucins is critical for the production of the mature slime.” (Herr et al. 2010: 1092; in-line citations removed from quote)

“When agitated, Atlantic hagfish (*Myxine glutinosa*) produce large quantities of slime that consists of hydrated bundles of protein filaments and membrane-bound mucin vesicles from numerous slime glands. When the slime exudate contacts seawater, the thread bundles unravel and the mucin vesicles swell and rupture. Little is known about the mechanisms of vesicle rupture in seawater and stabilization within the gland, although it is believed that the vesicle membrane is permeable to most ions except polyvalent anions. We hypothesized that the most abundant compounds within the slime gland exudate have a stabilizing effect on the mucin vesicles. To test this hypothesis, we measured the chemical composition of the fluid component of hagfish slime exudate and conducted functional assays with these solutes to test their ability to keep the vesicles in a condensed state. We found K^+ concentrations that were elevated relative to plasma, and Na^+, $Cl^–$ and Ca^{2+} concentrations that were considerably lower. Our analysis also revealed high levels of methylamines such as trimethylamine oxide (TMAO), betaine and dimethylglycine, which had a combined concentration of 388 mmol $l^{–1}$ in the glandular fluid. In vitro rupture assays demonstrated that both TMAO and betaine had a significant effect on rupture, but neither was capable of completely abolishing mucin swelling and rupture, even at high concentrations. This suggests that some other mechanism such as the chemical microenvironment within gland mucous cells, or hydrostatic pressure is responsible for stabilization of the vesicles within the gland.” (Herr et al. 2010: 1092)

“⋯[hagfish] slime originates as a two-component glandular exudate comprised of coiled bundles of cytoskeletal intermediate filaments (thread skeins) and mucin vesicles…Deployment of the thread skeins involves their unraveling in a fraction of a second from a 150 μm-long ellipsoid bundle to a thread that is 100x longer. We hypothesized that thread skein deployment requires both vigorous hydrodynamic mixing and the presence of mucin vesicles, both of which are required for whole slime deployment. Here we provide evidence that mixing and mucin vesicles are indeed crucial for skein unraveling.” (Winegard & Fudge 2010: 1235)

“Our video deployments confirmed the hypothesis that hagfish use slime secretion as an effective defence mechanism against predation. The footage we obtained showed that slime can affect gill-breathing predators by clogging gills, likely by increasing the resistance to water flow.” (Zintzen et al. 2011: 2)

"What triggers the slime secretion is likely to be direct skin stimulation by a predator. Active slime secretion was not observed when the potential predator approached the hagfish, but only began when the predator either tried to bite or engulf the hagfish. The mechanism of localised control and coordination of slime glands, as observed in our video footage, has been documented in laboratory studies and was highly effective to allow a full escape. It was also fast enough to prevent any injury to the hagfishes." (Zintzen et al. 2011: 3)

參考文獻清單與連結 (REFERENCE LIST)

Downer, J. (2002). *Weird nature: an astonishing exploration of nature's strangest behavior*. Firefly Books.

Herr, J. E., T. M. Winegard, M. J. O'Donnell, P. H. Yancey, P. H., and D. S. Fudge. (2010). Stabilization and swelling of hagfish slime mucin vesicles. *Journal of Experimental Biology* 213: 1092-1099. (https://dx.doi.org/10.1242/jeb.038992)

Winegard, T. M. and D. S. Fudge. (2010). Deployment of hagfish slime thread skeins requires the transmission of mixing forces via mucin strands. *Journal of Experimental Biology* 213: 1235-1240. (https://dx.doi.org/10.1242/jeb.038075)

Zintzen, V., C. D. Roberts, M. J. Anderson, A. L. Stewart, C. D. Struthers, and E. S. Harvey. (2011). Hagfish predatory behaviour and slime defence mechanism. *Scientific Reports* 1: 131. (https://www.nature.com/articles/srep00131)

Bernards, M. A., I. Oke, A. Heyland, and D. S. Fudge. (2014). Spontaneous unraveling of hagfish slime thread skeins is mediated by a seawater-soluble protein adhesive. *Journal of Experimental Biology* 217: 1263-1268. (https://dx.doi.org/10.1242/jeb.096909)

延伸閱讀: Harvard 或 APA 格式

生物系統延伸資訊連結 (LEARN MORE ABOUT THE LIVING SYSTEM/S)

https://en.wikipedia.org/wiki/Myxinidae
https://www.onezoom.org/life/@myxinidae
https://eol.org/pages/8908

撰寫/翻譯/編修者與日期

鍾曉宜翻譯 (2020/05/06)；許秋容編修 (2020/06/03)；譚國鋈翻譯/編修 (2020/06/09)

AskNature 原文連結

https://asknature.org/strategy/slime-rapidly-expands-and-protects/