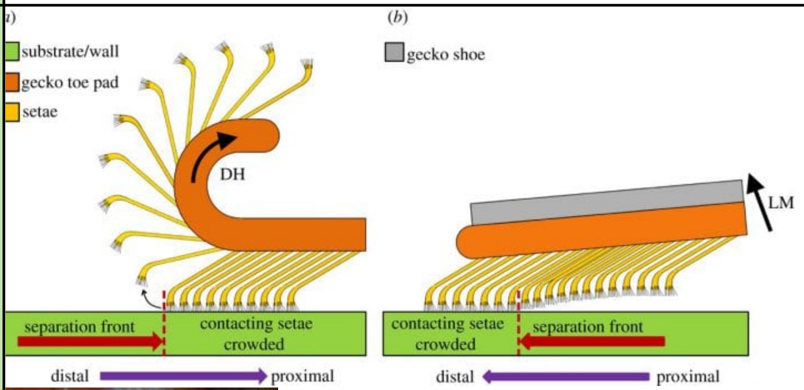
生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	腳的黏性超級強但不會弄髒 (Feet Are Super Sticky but Don’t Get Dirty)
生物系統 LIVING SYSTEM	大壁虎 *Gekko gecko* (Tokay gecko)
功能類別 FUNCTIONS	#在固體中/上移動 #暫時性附著 #Move in/on solids #Attach temporarily
作用機制標題	壁虎的腳使用原子力來黏在表面上，透過將污染物從腳趾上甩開來保持清潔 (Feet of the tokay gecko use atomic forces to stick to surfaces, but stay clean by flinging contaminants off toes.)
生物系統/作用機制示意圖	 

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

策略, 第**1**部分

壁虎因牠們能夠爬上各種表面的黏性腳而聞名。牠們的腳趾墊 (toe pad) 被數百萬根被稱為剛毛 (setae)，像頭髮一樣的凸起 (projection) 所覆蓋，每個凸起的長度約為100 µm, 直徑為5 µm。剛毛進一步分岔成數百個奈米尺度的結構，其末端是稱為匙突 (spatulae) 的微小圓盤。這種多尺度 (multi-scale) 的分岔為壁虎腳提供了非常大的表面積。匙突透過在所有分子之間都會出現的凡德瓦力 (van der Waals force) 黏附在表面上。儘管這些力單獨來看很弱，但所有匙突組合成的大片表面積，意味著這些力能疊加並使壁虎達成其著名的壯舉。

策略, 第**2**部分

如果此系統使壁虎腳能夠黏附在物體表面上，那為什麼牠們也不會黏上灰塵和其它顆粒呢？壁虎透過動態性自我潔淨 (dynamic self-cleaning) 來保持黏性腳的乾淨。

對於壁虎 (*Gekko gecko*)，當牠的腳從行走的表面上脫離時，其腳趾具有過度伸展 (hyperextend) 的能力：腳趾以尖端開始從表面剝離，並捲曲離開該表面（相比之下，人的手指無法隨意過度伸展，並且在彎曲時有更多功能）。當腳趾尖端的剛毛開始被拉動時，由於匙突仍附著在表面上，它們會稍微伸展並儲存彈性能。隨著腳趾繼續往後捲起，剛毛突然從基質 (substrate) 上脫離。它們的彈力特性和隨著腳趾捲起和向後伸展而攤開的能力會造成投擲運動，該運動可清除匙突上和匙突之間卡住的顆粒。此動作從腳趾尖端到基部順序進行，直到整隻腳都騰空。當壁虎的腳趾過度伸展並產生此種投擲運動（研究人員稱之為「剛毛跳離 (setal jump-off)」時，它們擺脫污染物顆粒的速度是腳趾沒有過度伸展的兩倍。經過四個步驟，腳可以恢復接近80％的黏合力。

這種動態機制似乎與其它用於自我潔淨的被動機制同時進行，例如當污染物更容易附著在基質上而不是壁虎腳時，就能達到顆粒清除作用。結果，在行走過程中污染物顆粒不僅從剛毛脫落，也會堆積在基質上。

The Strategy, Part 1

Geckos are renowned for the sticky feet that enable them to climb a variety of surfaces. Their toe pads are covered in millions of small hair-like projections called setae, which are each about 100 µm long and 5 µm in diameter. The setae branch further into hundreds of nano-scale structures that end in tiny discs called spatulae. This multi-scale branching gives gecko feet a very high surface area. Spatulae stick to surfaces via the van der Waals forces that occur between all molecules. Although these forces are individually weak, the high surface area of all the spatulae combined means the forces add up and enable geckos to perform their famous feats.

The Strategy, Part 2

If this system enables gecko feet to cling to surfaces, why don't they also cling to dust and other particles? Geckos appear to keep their sticky feet clean and functional through dynamic self-cleaning.

For the tokay gecko (*Gekko gecko*), when its foot detaches from a surface the animal is walking on, its toes have the ability to hyperextend: the toes peel off the surface starting at the tip, and curl up away from the surface (human fingers, for comparison, cannot voluntarily hyperextend, and are much more functional in flexion). When the setae at the tip of the toe are first pulled, they stretch a little and store elastic energy as the spatulae are still attached to the surface. As the toe continues to curl up, the setae suddenly detach from the substrate. Their stretchy nature and ability to spread out as the toe curls up and back results in a flinging motion that can dislodge particles caught on and between the spatulae. This action proceeds sequentially from the tip to the base of the toe, until the entire foot is free. When gecko toes hyperextend and produce this flinging motion (what researchers call "setal jump-off"), they shed contaminating particles twice as fast as they would if the toes didn't hyperextend. After four steps, the feet can regain almost 80% of their adhesive force.

This dynamic mechanism appears to work in concert with other passive mechanisms for self-cleaning, like particle removal that results when contaminants are more attracted to the substrate than the gecko foot. As a result, contaminating particles are both flung off the setae and deposited on the substrate during walking.

文獻引用 (REFERENCES)

「更快速的自我潔淨以及對壁虎腳趾在非無塵環境 (non-dust-free environment) 中長時間保持清潔和功能的觀察，推測有一種動態性自我潔淨機制在壁虎運動 (locomotion) 過程中能有效地移除灰塵顆粒。由於附著力 (adhesion force) 性質，不對稱幾何形狀 (asymmetric geometry) 以及由壁虎透過腳趾過度伸展 (digital hyperextension, DH) 引起從遠端到近端 (distal-to-proximal) 的剝離，旋轉的剛毛突然從附著的基質上鬆開，產生了足夠高的加速度 (acceleration)，足以從腳趾墊上去除灰塵顆粒。儘管某些灰塵可以被靜態地去除，但動態自我潔淨增加了另一個能更強烈地去除黏附在剛毛上的顆粒。」(Hu et al. 2012: 2789)

"More rapid self-cleaning and the observation that gecko toes remain clean and functional for long periods of time in non-dust-free environments suggest a dynamic self-cleaning mechanism that efficiently removes dirt particles during animal locomotion. Because of the nature of the adhesion force, asymmetric geometry and animal triggered distal-to-proximal peeling via DH, the rotating setae suddenly release from the attached substrate, generating acceleration high enough to dislodge dirt particles from the toe pads. While some dirt can be removed statically, the dynamic self-cleaning adds another dimension to remove the particles that more strongly adhere to the setae." (Hu et al. 2012: 2789)

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