# 生物策略表

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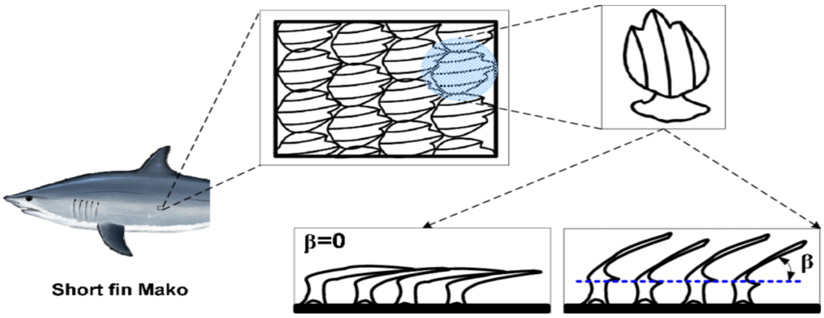
| **類別** | 生物策略 (Strategy) |
| **生物策略**<br>STRATEGY | 鱗片操縱水流<br>(Scales Manipulate Flow) |
| **生物系統**<br>LIVING SYSTEM | 鯊魚 (Sharks) |
| **功能類別**<br>FUNCTIONS | #在液體中移動<br>#Move in/on Liquids |
| **作用機制標題** | 鯊魚的鱗片透過操縱體表附近的流體流動來影響游泳時的阻力和推力。<br>(Scales on sharks influence drag and thrust during swimming by manipulating fluid flow next to the body.) |
| **生物系統/作用機制示意圖**<br>(確認版權、註明出處；畫質) | <br>https://www.researchgate.net/figure/A-schematic-representation-of-scales-on-the-short-fin-mako-sharks-and-denticular_fig1_350361807 |

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

某些種類的鯊魚可以用 50 公里/小時（31 英里/小時）的驚人速度游泳。它們的皮膚覆蓋著被稱為盾鱗（字面意思是「皮齒」）的骨質鱗，通常為 0.2-0.5 毫米，具有在縱向脊上沿身體軸線排列的細小規則間隔（30-100 微米）。長期以來，人們一直假設鯊魚的鱗片透過管理最靠近皮膚的水流來減少阻力，而且鯊魚的盾鱗可能有助於渦流（在低壓區旋轉的水）附著在鯊魚身體的特定區域，從而產生更大的吸力和向前的推力。因此，鯊魚的盾鱗除了減少阻力之外還可以透過增加推力來提高游泳速度

然而，鱗片紋理只是影響鯊魚皮膚流體動力學的因素之一。實驗室實驗表明，與去除盾鱗的表面相比，覆蓋鯊魚皮的表面以及合成仿製品的游泳速度更快（並且可能減少了阻力）。但這種速度的增加只有在紋理表面被允許彎曲時才會發生（就像鯊魚身體在野外一樣），而不是當它保持剛性時。為什麼存在這種差異仍在調查中。當身體彎曲時，鯊魚鱗片能夠以超過 30-50° 的角度豎立，這可能會改變流體流動的性質。

關於鯊魚盾鱗減少阻力的有效性仍存在爭議。最近一項使用電腦進行的研究發現，與沒有鯊魚皮的平盤相比，有鯊魚皮的阻力增加了 45-50%。這些研究人員推測，盾鱗的三維形狀與局部流動相互作用，增加了阻力。然而，值得注意的是，模型做出了必要的簡化假設，包括盾鱗裝在剛性表面和直立的盾鱗靜止角度。需要進一步的研究，包括實證研究，來解決這些截然不同的結果。

Some species of sharks can swim at impressive speeds of 50 km/h (31 mph). Their skin is covered in bony scales called dermal denticles (literally ‘skin teeth’), generally 0.2-0.5 mm small, with fine regularly spaced (30–100 µm) longitudinal ridges aligned along the body axis. It has long been hypothesized that shark scales reduce drag by managing the water flow closest to the skin. In addition, shark denticles may help vortices (low-pressure regions of swirling water) stay attached to particular areas of the shark's body, resulting in more suction and forward thrust. Thus, a shark's denticles may increase swimming speeds by increasing thrust in addition to reducing drag.

Scale texture is just one of the factors that can influence shark skin hydrodynamics, however. Laboratory experiments have revealed that surfaces covered with shark skin, as well as synthetic replicas, experience faster swimming speeds (and presumably decreased drag) compared to surfaces with denticles removed. But this increase in speed only occurred when the textured surface was allowed to flex and bend (as a shark's body would in the wild), and not when it was kept rigid. Why this difference exists is still under investigation. The shark scales' ability to bristle in excess of 30-50˚ angles when the body bends may change the nature of fluid flow.

There is still debate regarding shark denticles' effectiveness at reducing drag. A recent computational study found that shark skin experienced increased drag by 45-50% when compared to a flat plate without shark skin. These researchers speculate that the three-dimensional shape of a denticle interacts with local flow in such a way that it increases drag. However, it is important to note that this model made necessary simplifying assumptions, including a rigid surface on which the denticles are mounted and a static angle of bristling. Further research, including empirical studies, will be required to address these contrasting results.

## 文獻引用 (REFERENCES)

「雖然盾鱗類似微壕溝，但這兩種鯊魚皮排列都會使總阻力增加 44%-50%，而微壕溝減少 5% 的阻力。流場模擬分析表明，盾鱗周圍的湍流是高度三維和分離的，形成的阻力占總阻力的 25%。盾鱗複雜的三維形狀產生了以強二次流為主的平均流，與主要是二維的微壕溝產生的平均流形成鮮明對比。” (Boomsma and Sotiropoulos 2016:035106-1)

「…在無溝雙髻鯊和黑邊鰭真鯊這兩個物種和上，鱗片很容易透過觸摸移動到超過 30 度的角度？。對短鰭灰鯖鯊盾鱗的極端直立角度進行建模的實驗證實了在盾鱗腔內嵌入式渦流的形成。” (Lang et al. 2008:7)

「越來越多的證據表明，透過盾鱗的作用減少阻力，最有可能是透過減少鱗片表面附近的湍流橫流來實現的，從而減少剪切應力，並透過控制身體周圍的水流分離來減少壓力阻力。 ” (Motta et al. 2012:1096)

“我們假設短鰭灰鯖鯊側面盾鱗的可直立性質可以減少這種快速遊動的鯊魚在水柱中游動時的逆流、回流和壓力阻力”(Motta et al. 2012:1108)

「…鯊魚的盾鱗對移動中的剛性鯊魚皮箔沒有有益的運動作用，但是與去除盾鱗的鯊魚皮膜相比，盾鱗確實顯著提高了柔性鯊魚皮膜箔的游泳性能（平均提高了 12.3%） …」(Oeffner and and Lauder 2012:791)

「…表面上存在的盾鱗因此改變了彎曲箔片表面附近的流動環境，使得前緣渦流更緊密地粘附在箔片表面…箔片表面上的壓力越低，箔片表面越靠近渦核靠近箔片表面，推力

越大……這一結果表明，皮齒的一個重要作用是增強推力，而不僅僅是減少阻力。”
(Oeffner and Lauder 2012:794)

“Although the denticles resemble riblets, both sharkskin arrangements increase total drag by 44%-50%, while the riblets reduce drag by 5%. Analysis of the simulated flow fields shows that the turbulent flow around denticles is highly three-dimensional and separated, with 25% of the total drag being form drag. The complex three-dimensional shape of the denticles gives rise to a mean flow dominated by strong secondary flows in sharp contrast with the mean flow generated by riblets, which is largely two-dimensional.” (Boomsma and Sotiropoulos 2016:035106-1)

“… on both species [S. mokarran & C. limbatus] the scales were easily moveable to the touch to angles in excess of 30?. Experiments modeling an extreme angle of bristling for shortfin mako denticles confirmed the formation of embedded vortices within the inter-denticular cavities.” (Lang et al. 2008:7)

“Mounting evidence indicates that drag reduction [via the role of dermal denticles] most likely occurs by reducing turbulent cross-flow near the scale surface, thereby reducing shear stress, and by control of flow separation around the body, which would reduce pressure drag.” (Motta et al. 2012:1096)

“We hypothesize that the erectable nature of the placoid scales along the flanks of the shortfin mako shark allows a reduction of flow reversal, backflow, and pressure drag as this fast-swimming shark maneuvers through the water column.” (Motta et al. 2012:1108)

“…shark denticles had no beneficial locomotor effect on the moving rigid shark skin foils, [but] denticles did improve swimming performance significantly (by an average of 12.3%) on flexible shark skin membrane foils compared with those in which the denticles had been removed…

“…The presence of denticles on the surface thus alters the flow environment near the flexing foil surface in such a manner that the LEV [leading edge vortex] adheres more closely to the foil surface…The lower the pressure on the foil surface and the closer the vortex core is to the foil surface, the higher the thrust force…This result suggests that one important effect of the skin denticles is to enhance thrust, and not simply to reduce drag.” (Oeffner and Lauder 2012:794)

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