生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	最大化骨頭剛性與強度 (Bone maximize stiffness and strength)
生物系統 LIVING SYSTEM	雀形目 Passerine
功能類別 FUNCTIONS	#改變材料特性 #在氣體中移動 #形狀最佳化 #物理性組成結構 #Modify material characteristics #Move in/ through gases #Optimize shape/ materials #Physically assemble structure
作用機制標題	鳥類的骨骼透過增加密度來最大化相對於體重的剛性與強度 (The bones of birds maximize stiffness and strength relative to weight by increasing density.)
生物系統/作用機制示意圖	

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

文獻引用 (REFERENCES)

「鳥類的骨骼普遍被描述成是輕量的，是為了要使飛行所耗費的能量最小化。從功能上的角度來看，動物的體重（質量）相對於能產生升力的表面，是飛行代謝消耗的一項決定性指標。鳥類已經演化出許多可以減少體重的適應，並反映在骨骼的構形，其中包含許多與骨骼強化和硬化有關。然而此在鳥類領域中鮮少被研究，但骨骼組織的材料特性也能影響骨頭強度及剛性 (stiffness)。在這項研究中，我使用了氦氣置換測量法，計算了雀形目鳥類 (passerine bird)、齧齒動物及蝙蝠的顱骨 (cranium)、肱骨 (humerus) 及股骨 (femur) 的質量及體積。我發現就平均而言，鳥類的骨頭密度最大，其次為蝙蝠類。而隨著密度的增加，剛性與強度也會隨之增加。這兩項最佳化的標準，都被用於人類設計出具備強度與剛性，但同時又能輕量的機翼。依此類推，鳥類與蝙蝠的骨質密度增加現象，反映了最大化骨骼強度與剛性，同時能夠最小化降低骨頭質量與體積的適應性。這些數據顯示骨頭形狀與骨頭組織的材料特性皆在飛行的演化中扮演了重要角色。也解答了為何鳥類骨骼看起來雖然瘦薄且纖弱，但佔總體重的比例卻和陸地哺乳動物一樣大的難題。」

"The skeletons of birds are universally described as lightweight as a result of selection for minimizing the energy required for flight. From a functional perspective, the weight (mass) of an

animal relative to its lift-generating surfaces is a key determinant of the metabolic cost of flight. The evolution of birds has been characterized by many weight-saving adaptations that are reflected in bone shape, many of which strengthen and stiffen the skeleton. Although largely unstudied in birds, the material properties of bone tissue can also contribute to bone strength and stiffness. In this study, I calculated the density of the cranium, humerus and femur in *passerine* birds, rodents and bats by measuring bone mass and volume using helium displacement. I found that, on average, these bones are densest in birds, followed closely by bats. As bone density increases, so do bone stiffness and strength. Both of these optimization criteria are used in the design of strong and stiff, but lightweight, manmade airframes. By analogy, increased bone density in birds and bats may reflect adaptations for maximizing bone strength and stiffness while minimizing bone mass and volume. These data suggest that both bone shape and the material properties of bone tissue have played important roles in the evolution of flight. They also reconcile the conundrum of how bird skeletons can appear to be thin and delicate, yet contribute just as much to total body mass as do the skeletons of terrestrial mammals”

參考文獻清單與連結 (REFERENCE LIST)

E. R. Dumont. (2010). Bone density and the lightweight skeletons of birds. *Proceedings of the Royal Society B: Biological Sciences* 277: 2193-2198. (https://royalsocietypublishing.org/doi/10.1098/rspb.2010.0117)

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/passeriformes
https://www.onezoom.org/life/@passeriformes
https://eol.org/pages/1596

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AskNature 原文連結

https://asknature.org/strategy/bones-maximize-stiffness-and-strength/