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Internal structure of scaly armor enables bite resistance in the African Pangolin

Natural materials often exhibit excellent mechanical properties that are packaged within lightweight structures. This exceptional performance of natural materials is achieved through efficient use of architectural design, which is difficult to replicate synthetically. Recent efforts in solid mechanics research have focused on using biological materials and structures as model systems to reveal natural design strategies that can be implemented in synthetic fabrication. Indeed, "bioinspiration" is an active area of scientific inquiry that has delivered novel concepts for a diverse set of applications including: self-sharpening cutting tools, building designs for efficient cooling and heating, and aerodynamic components for high-speed trains.

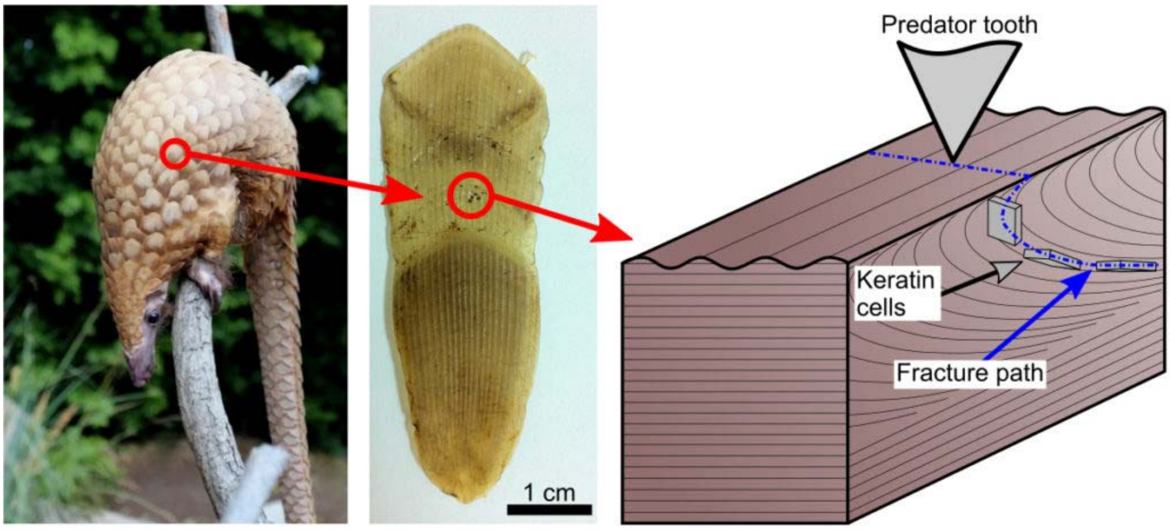

Fig. 1. Left: An African pangolin (Manis Tricuspis). Middle: An example of a scale of the African pangolin. Right: A schematic of a predator bite and the resulting fracture path that follows the keratin cells. The image of the African pangolin (left) is reprinted using a Creative Commons ShareAlike 3.0 license (Николай Усик / http://paradoxusik.livejournal.com/ (Own work), via Wikimedia Commons).

Within this context, the pangolin is a nocturnal insectivore found primarily in parts of Africa and Asia that possesses a protective armor constructed from a network of overlapping scales. These scales are made from keratin (the same material from which finger nails and hair are constructed), but surprisingly, are strong enough to resist bites from predators such as: lions, tigers, and leopards. This excellent protection is a source of great interest for the design of lightweight armors, given that it is achieved from structures consisting of relatively weak components. In this study, we have examined the protective characteristics of pangolin scales by studying their fracture toughness (*i.e.*, the amount of energy required to propagate a crack in the pangolin scale). From these mechanical measurements, we have learned that the high fracture toughness in the pangolin scales is derived from the organization of keratin in the scale structure – highlighting the critical role of material architecture. More specifically, we have shown that propagating cracks can be directed along specific directions that are modulated by the keratin structure. In this manner, cracks can be deflected away from the soft tissues under the scales – thereby serving as an effective defense to predation. We also show that increased humidity plays a critical role in improving the fracture toughness of pangolin scales. This effect is analogous to the brittle fracture of finger nails when they are dry, as compared to the relatively tough response of finger nails that are well hydrated. Within the theme of bioinspiration, our results here suggest design strategies for synthetic armors that leverage the crack deflection mechanisms of pangolin scales.

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