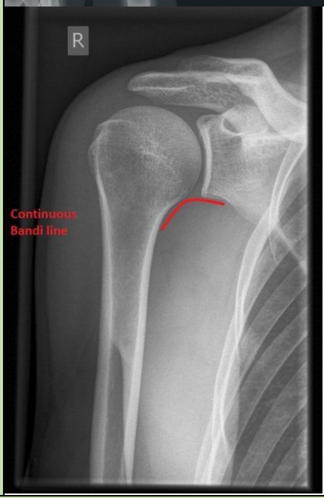
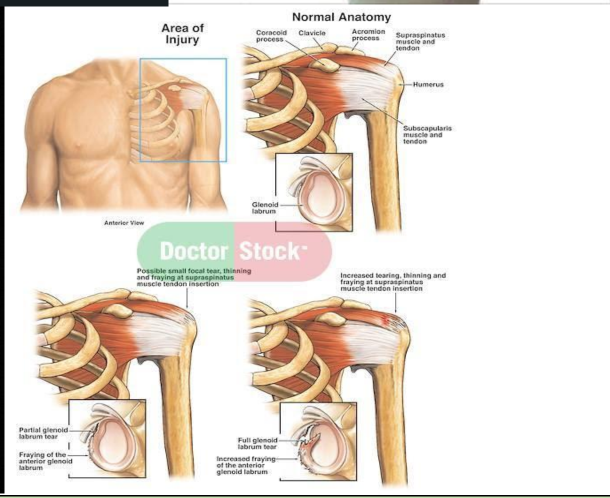
生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	肩關節調控應力 (Shoulder Joint Manages Stress)
生物系統 LIVING SYSTEM	人類 *Homo sapiens* (Humans)
功能類別 FUNCTIONS	#永久性附著 #Attach Permanently
作用機制標題	人類肩迴旋肌透過額外的易曲折區域來調控應力 (Rotator cuff in humans manages force via an extra pliable region)

生物系統/作用機制示意圖





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

將兩種特性差異非常大的材料連接在一起，無論是對於自然界還是人工製造方面都是一大挑戰。當不同的材料連接時，力量會積聚在接合點並導致失效 (failure)。這裡的失效是指「疲勞 (fatigue)」，在壓力低於材料自身能夠承受的程度時也能發生。在工程上，就如同在自然界一樣，失效幾乎都是發生在疲勞點 (point of fatigue)，而不是在散裝材料 (bulk material) 上。

自然界中最大的材料差異 (materials discrepancy) 之一是透過肌腱 (tendon) 連接肌肉到骨頭上。這對肩膀尤其重要。肩膀關節不僅要應付肢體 (limb) 本身的重量，還要應付我們可能攜帶其他任何物品的重量。在 2019 年，來自喬治亞 (Georgia) 的 Lasha Talakhadze 創下舉重的世界紀錄，他成功舉起 264 公斤 (582 磅)，相當於大約 4 個人的重量。那是非常重的重量，全都壓在他的肩膀上！

降低疲勞風險的其中一種方法，就是以一種材料特性到另一種的梯度作為過渡區域 (transition zone)將不同材料連接在一起。在肩迴旋肌 (rotator cuff)（將肩部肌肉連接到手臂上端的肌腱列 tendon array）呈現一個梯度，它比簡單的過渡要複雜得多。從鎖骨 (collarbone) 開始並移向肌腱，越遠離骨頭的組織越柔軟且更柔韌 (flexible)。組織的軟化遵循著 S 形曲線模式 (sigmoidal pattern)，即是柔韌性隨著與骨頭的距離產生變化，靠近骨頭的區域變化得比較慢，而遠離骨頭的柔韌性則變化得較快。類似的過渡也發生在連結處的肌腱末端。然而，並不如我們可能預期的肌腱到骨頭之間有平滑過渡，即肌腱會變得像骨頭般堅硬，該組織反而是過渡成為更易曲折 (pliable) 的區域。這代表梯度是從骨頭開始，在中段會比骨頭或肌腱都還要更柔韌，然後稍微變得結實以配合肌腱的特性。這個特別易曲折的區域似乎可以應付應力 (stress) 的產生，防止應力在關節的任何地方累積，並減少疲勞帶來的傷害。

肩膀的關節需要一些身體中最強壯的肌肉，透過非常小的附著點連接到手臂的骨頭上。

Joining together materials with very different properties is challenging in nature as well as in manufacturing. When different materials are joined, forces can build up at the interface that cause failure. This type of failure is called “fatigue” and it can occur at lower levels of stress than each material could withstand on its own. In engineering, as in nature, failure almost always occurs at points of fatigue, and not in the bulk material.

One of the largest materials discrepancies in nature is the joining of muscle to bone via tendon. This is particularly important at the shoulder, where not only must the joint manage the weight of the limb itself, but also anything else we might carry. In 2019, the weightlifting world record was set by Lasha Talakhadze of Georgia, who successfully lifted 264 kg (582 lb), the equivalent of about 4 people. That’s a lot of weight, all going through his shoulders!

One way of reducing the risk of fatigue is to join different materials with a transition zone that has a gradient of properties from one to the other. In the rotator cuff (the tendon array that attaches the muscles of the shoulder to the upper end of the arm) there is a gradient, but it is more complex than a simple transition. Starting at the collarbone and moving towards the tendon, the tissue is softer and more flexible the further away it is from the bone. The softening follows a sigmoidal pattern, which means the change in flexibility with distance from the bone is slow near the bone, and becomes more dramatic further away. A similar transition occurs at the tendon end of the join. However, instead of becoming more rigid like bone, as we might expect for a smooth transition from tendon to bone, this tissue also transitions into a region that is more pliable. This means that the gradient starts with bone, becomes more flexible than either bone or tendon in the middle, and then firms up slightly to match the properties of tendon. This extra pliable region seems to manage the stresses as they arise, preventing their build up elsewhere in the joint and reducing injury due to fatigue.

The shoulder joint requires some of the strongest muscles in the body to attach to the bone of the arm via very small attachment sites.

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