A Multiscale Ultrastructural, Chemical and Mechanical Investigation of the Musk Ox (Ovibus Moschatus) Horn

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Abstract

Male musk oxen, weighing up to 400 kg, engage in head-to-head collisions at speeds up to 50 km/hr during mating season, surviving repeated impacts over their lifetimes. This makes them a compelling subject for studying natural impact mitigation mechanisms. This research investigates the musk ox horn's microstructural and compositional changes at varying scales using a combination of complementary techniques including optical microscopy, backscattering electron microscopy (BSEM), micro-computed tomography (μCT), energy-dispersive X-ray spectroscopy (EDS), and X-ray diffraction (XRD). Here, a detailed multisale structural investigation of a sample taken from the primary impact zone (Fig.1(a)) of the musk-ox skull, is presented. It features four distinct regions: the impact surface, impact region, interface, and wave-like region (WLR) (Fig.1(a)), resembling structures in mantis shrimp (1). Here we show the musk ox horn's ultrastructure is similar to that of rhino horn and hooves, whereby hollow pores (known as tubules) are surrounded by circular rings of lamellae and separated by some intertubular material, similar to osteons in human cortical bone which may help manage crack propagation. (2-4). The large musk ox tubules are surrounded by smaller, open and closed tubules, this configuration may allow the horn to deform and absorb energy during collisions. Large tubules were demarcated by white lines resembling cement lines in bones, potentially deflecting or arresting microcracks (Fig.1(b)). The interface marks a transition to the organised, layered WLR, where major wave peaks are seen in the white vertical lines, interconnected by smaller wave structures. EDS analysis of all layers showed an elemental composition indicative of keratin (carbon, oxygen and sulfur) (5). Finally, compositional differences identified between the impact region and the WLR will be presented, along with their correlation to varying mechanical properties identified using nanoindentation stiffness and hardness measurements.

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