EFFECT OF SUPPLEMENTAL HEAT IN CAPTIVE AFRICAN LEOPARD TORTOISES (*STIGMOCHELYS PARDALIS*) AND SPURRED TORTOISES (*CENTROCHELYS SULCATA*) ON GROWTH RATE AND CARAPACIAL SCUTE PYRAMIDING

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Abstract

Carapacial scute pyramiding (CSP) is common in captive-raised turtles and tortoises. Several dietary and environmental hypotheses have been proposed to explain this phenomenon, but few have been scientifically investigated. The effect of increased heat exposure on CSP and growth was examined in juvenile African leopard (*Stigmochelys pardalis*) and spurred (*Centrochelys sulcata*) tortoises. Monthly measurements of individual tortoise surface temperature, length, height, width, weight, and pyramid height of treatment (heat) and control (no heat) groups for 2 years were higher in the treatment groups. Allometric comparison further revealed increased pyramiding in the treatment group. Humidity and diet did not differ between treatment and control groups. The results of this research investigation indicate that growth rate and CSP appear to be directly related and both increase with excess nocturnal heat. The significance of the atypical carapace growth and subsequent consequences for naturally occurring tortoise populations, especially in the context of global climate change, is unknown but requires further investigation. Copyright 2015 Elsevier Inc. All rights reserved.

Key words: Carapacial scute pyramiding; chelonian; deformity; pyramidal growth syndrome; shell; temperature

The order Chelonia is unique in the animal kingdom based on possession of an external shell composed of the dorsal carapace, the intermediate bridge, and the ventral plastron. Furthermore, chelonians are the only vertebrates whose limbs exist deep to their ribs. Shell growth is manifested via dynamics lacking in other vertebrates. Developmentally, the ribs become associated with carapacial dermis that eventually becomes the bony part of the shell. The vertebral neural arches are also incorporated in the shell at the carapacial midline.[1] Epidermal scutes are formed long before ossification of the dermal layer of the shell.[1] Although ossification of the ribs begins embryologically, dermal plates of the carapace do not ossify until after hatch. Complete ossification of the carapace may take several years in captive-raised tortoises (Heinrich ML, unpublished data). Despite lack of a congruency between epidermal scutes and dermal bony plates, the dermal layer is thought to play a major role in epidermal scute formation.[1]

Based on decades of knowledge accrued by laypersons and curators of zoological and educational institutions, many species of turtles and tortoises have been successfully maintained and reproduced in captivity. Subsequently, many species are readily available to the general public for captive care. With this influx of turtles and tortoises hatched and raised in captivity, an

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emergent phenomenon referred to as pyramidal growth syndrome or hump formation is common.[2] This phenomenon is manifested as individual carapacial scute pyramiding (CSP). The affected keratinized carapacial plate is elevated conically, forming a convex hump and a corresponding furrow or valley between the scutes as the individual grows. This deformity appears to be more prominent in the vertebral scutes. When performing necropsies on animals exhibiting CSP, the authors have observed a thickening of the underlying dermal bone directly related to the overlying growth area at the epidermal carapacial scute margins. The ventral surface of the dermal bones exhibits a concavity internally in association with the dorsal convexity of the outside carapacial scutes. Further, separation of the vertebral column from the carapace and the bridging of extremely thin bone from the dorsal vertebral body to the carapace were observed (Fig. 1). Although CSP is rare to nonexistent in most species living in their natural habitats, it has been observed in free-living African leopard (*Stigmochelys pardalis*), common tent (*Psammobates tentorius tentorius*), African spurred (*Centrochelys sulcata*), and Indian star (*Geochelone elegans*) tortoises.[3,4]

Many factors have been hypothesized as the underlying etiology of pyramidal growth in chelonians, but few have been scientifically investigated. Possible causes of pyramidal growth in chelonians that have been anecdotally proposed in the scientific literature as well as nonscientific publications and on the Internet include improper humidity, various nutritional or mineral imbalances, endoparasites, overeating, lack of sunlight, increased growth rate, improper environmental temperature, lack of mechanical abrasion on the shell, and lack of exercise. Humidity and dietary protein effects on pyramiding in African spurred tortoises were found to be significant and nonsignificant (minor positive effect on pyramiding), respectively, in pyramidal growth syndrome.[2] Others investigated the digestibility of calcium (Ca), magnesium (Mg), and phosphorous (P) using 2 diets in Hermann's tortoises (*Testudo hermanni*).[5] An increase in digestibility of Ca and Mg was associated with a diet containing more Ca at a Ca/P = 6:1 as opposed to a diet Ca/P = 3:1 with no CSP being observed in the study.[5] Further, differing percentages of Ca and P supplementation in red-eared sliders (*Trachemys scripta elegans*)[6] and Ca, Mg, and P digestibility studies performed on captive-hatched Galapagos tortoises (*Geochelone nigra*)[7] did not yield pyramiding. Dietary calcium levels have also been studied in African leopard tortoises with no CSP noted in any of the treatment groups. However, various growth rates were observed as well as dystrophic calcification and hypocalcification.[8]

Chelonians, as with other poikilotherms, are significantly dependent upon appropriate environmental temperatures to optimize metabolic processes and subsequent growth. Turtles and tortoises have evolved in various habitats to survive with substantial daily and seasonal environmental changes related to temperature, humidity, and a host of other variables dictating environmental living conditions. Chelonian species have adapted to major seasonal changes including freezing winter temperatures and dry seasons where optimal metabolism and food availability are severely compromised. During their active periods, chelonians can be provided with all necessary variables for sustaining life, but if heat is missing from the equation, metabolic functions would suffer, disease would occur, and ultimately the animal would die. Recommendations from veterinarians, pet store owners, other professionals, and laypersons often reduce the environmental extremes in which these animals have evolved. There is also a tendency to prolong or provide excessive or improper amounts of seemingly favorable variables (e.g., food, longer photo period, artificial heat cycles) while maintaining these animals in captivity. Increased growth rates and early onset of sexual maturity have been reported in captive African spurred tortoises when compared with their free ranging counterparts.[9] Captive-raised Galapagos tortoises at Zoo Zurich exhibited distinct differences in growth rate from those raised at the Charles Darwin Research Station in the Galapagos Islands. The zoo-raised tortoises had increased carapacial length and body weight and exhibited slight pyramiding compared with tortoises experiencing natural conditions at Charles Darwin Research Station. Increased dietary nutrients and decreased dietary fiber were implicated in the observed differences.[10] The authors have also observed that slower-growing chelonians appear to show less CSP.

Beyond purely a cosmetic deformity, CSP is of concern for tortoise health based on compromise of the associated neurologic, musculoskeletal, and internal organ structures of affected animals. The consequences of this deformity for the health and longevity of captive chelonian species remain