

NOTES AND FIELD REPORTS

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Bifid Tail Regeneration in a Turtle, *Emydura* sp. (Testudines: Chelidae)

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ABSTRACT. – Partial tail regeneration in a turtle is described grossly and radiographically. Turtles do not have autotomous tails and have not been described to regenerate lost tails, but this specimen regenerated a partial tail following presumed trauma. The regenerated tail had dense segmented tissues, possibly cartilaginous.

It is often difficult to define clearly the borders between regeneration and other repair processes such as wound healing. Tissue repair, a basic mechanism, is the proliferation of cells in a specific tissue through mitotic divisions. Epimorphic regeneration, however, involves epidermal wound healing, dedifferentiation of cells and redifferentiation into several tissue types (Goss, 1969; Reichman, 1984). Regeneration, thus, can be defined as the ability to reproduce relatively complicated organs or structures after they have been lost through trauma or other causes.

The tail of certain reptiles has extensive powers of regeneration. The best tail regeneration capabilities are found in reptiles that show caudal autotomy, for example many lizards (Squamata) and *Sphenodon* (Rhynchocephalia). The new tail is generally not a perfect replica of the original. For example, the skeleton of the regenerate consists of a cartilage tube and not of new bony vertebrae; its color, size, and the pattern of the epidermal scales may be different from the original tail. The gross form of regenerated tail scales often differs from the original form, and tubercles and spines may be absent or irregular. Nonautotomous squamates such as many agamids, certain iguanids, the varanids, and most snakes appear to have little or no ability to regenerate the tail. If part of the tail is lost through trauma, the stump heals over with very little or no elongation. The tail of certain crocodylians, all of which are nonautotomous, may show a limited power of regeneration (Bellairs and Bryant, 1985). Thus, of the extant orders of reptiles, tail regeneration capabilities have been demonstrated in Squamata, Rhynchocephalia, and Crocodylia.

Sometimes lizards and *Sphenodon* are found in nature with bifid tails, with a regenerate growing from an original tail or joined to another regenerate. Such abnormalities result from incomplete autotomies or ruptures and from other injuries, either to original tails or to previous regenerates (Bellairs and Bryant, 1985).

Very little is known about tail repair in the non-autotomous turtles (Testudines). In their comprehensive review of regeneration in reptiles, Bellairs and Bryant (1985) did not even mention the chelonian tail. However, Davenport (1995) reported that, following amputation of the tail spur of an adult male *Testudo hermanni* (Testudinidae), including 2 mm of the *flexor caudae lateralis* muscle, the spur regenerated over a period of six years to a new spur measuring 4 mm in length; by twelve years the regenerated spur measured 8 mm in length and had regained the pattern, coloration, and formation typical for the species. This observation demonstrates that *T. hermanni* is able to regenerate the tail spur, a specialized integumentary appendage. Although it was not reported whether the vertebral column was damaged or involved in the regeneration process, the observation suggests that some tail regeneration may take place in chelonians.

Results. — I caught an adult male *Emydura* sp. (241 g body mass, 121.4 mm carapace length, 99.2 mm plastron length) with a bifid tail in a baited trap in a backwater pool of the Mitchell River in the Kimberley, Western Australia, on 14 September 2000. The specimen probably belongs to an undescribed taxon related to *Emydura australis*. I documented the bifid tail photographically and radiographically. Histology was not performed. At present the turtle is still alive in my collection.

From above, the posterior part of the tail is forked in the horizontal plane, with the projection to the left side being thicker than that to the right (Fig. 1). Some skin spans between the fork branches to give the tail the appearance of a triangular spatula with the broad end posteriorly. The left projection is relatively blunt and dark gray. It is part of the original tail that obviously lost its posterior portion (the branch is shorter than the typical tail of an adult male). The right projection protrudes like a spine and is lighter, although it shows some pigmentation dorsally. Viewed ventrally, the bifurcation starts just caudal to the cloacal opening; the original tail branch is darkly pigmented, while the accessory regenerate is whitish-yellow in color (Fig. 2). The original tail has a slight bend to the left side, but can move and bend in the way of a normal tail. Posterior to the cloacal opening a regenerated tail of about the same length, but thinner than the original tail, protrudes in the horizontal axis towards the right. This branch is rather rigid and does not flex or bend. The tips of both the original tail branch and the regenerate are slightly damaged (presumably due to the transport of the turtle), some bone and tissue is exposed at both tips (Fig. 1, 2).

The radiograph (Fig. 3) reveals that the left (original) projection is part of the original tail and contains ossified vertebrae, with those near the tip (a-e) appearing damaged. The last two caudal vertebra (a-b) appear especially damaged with possible evidence of chronic infection (osteomyelitis). What appears to be a small bone fragment (c) caudal to the last vertebra, may be the remnant of a missing vertebra. The original tail tip has probably been lost. A diffuse,

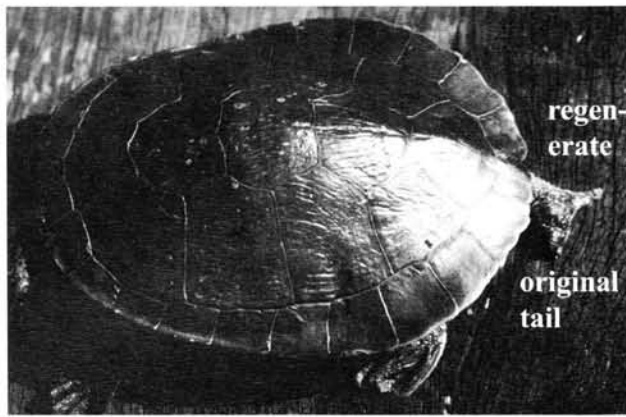


Figure 1. Dorsal view of adult male *Emydura* sp. with tail bifurcation in the horizontal plane. The thicker left branch is a part of the original tail, the right branch is the accessory regenerate.

pointed outgrowth towards the right, possibly cartilaginous or dense or calcified scar tissue or firm fibrous tissue, originates from the damaged portion of the original tail.

One vertebral body (d) shows over its whole length a dense outgrowth to the right side. This outgrowth is less calcified than the vertebra and is possibly cartilaginous. The adjacent cranial vertebral body (e) also shows a dense tissue outgrowth towards the right side, but this outgrowth originates only in the posterior half of the vertebra and points at an angle of about 125° to the posterior. A space (f), reminiscent of an intervertebral space, separates both outgrowths. Posteriorly towards the left follows a piece of dense tissue (g) that is about a third longer than and about twice as broad as a typical caudal vertebra. It narrows posteriorly and is separated from both vertebral outgrowths by a space (h) reminiscent of an intervertebral space. This tissue is followed posteriorly by another piece of about the same length (i), but which narrows to a pointed end. The two pieces also are separated from each other by a space (j) that is, however, less clearly defined than the anterior space (h).

The bones and the dense tissue in the tips of both the original tail and the accessory regenerate are not clearly defined in the radiograph. This indicates inflammatory processes and possibly chronic osteomyelitis.

Discussion. — Not all examples of double tails in reptiles can be ascribed to regenerative phenomena. Various degrees of Siamese twinning or axial bifurcation also have been reported. Regenerated tails of reptiles lack vertebrae but instead have cartilage tubes or rods. If both tails possess ossified vertebral columns, it can generally be assumed that axial bifurcation rather than regeneration is the cause of a bifid tail. Cartilage tubes or rods, however, indicate that a bifid tail is the product of a regeneration event (Bellairs and Bryant, 1985). The appearance of the bifid tail of the turtle described in this paper suggests that it is the consequence of a regenerative process and not of axial bifurcation: ossified vertebrae are only visible in the left branch, the original tail, whereas the structure of the right branch appears cartilaginous or other dense fibrous tissue and does not show the typical ossified structure of the tail vertebral column.

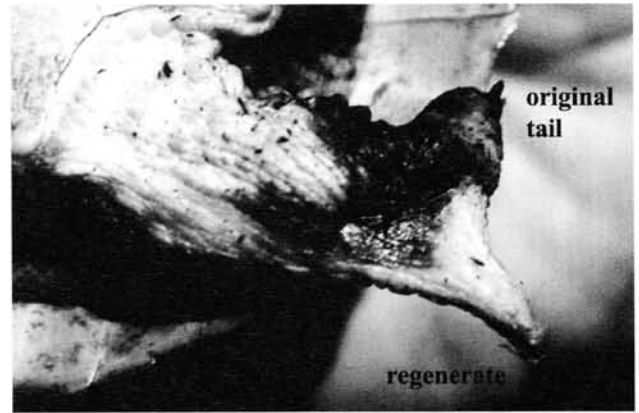


Figure 2. Ventral view of the bifid tail of the adult male *Emydura* sp. The upper branch is part of the original tail, the lower branch is the accessory regenerate.

Bifid tails in lizards have been produced experimentally by partly breaking the tail or damaging its vertebrae (Tornier, 1897; Slotopolsky, 1922). Tornier (1897) obtained extra tails containing two cartilage tubes in lizards by damaging adjacent vertebrae of original tails. It is believed that injuries have to involve damage to the spinal cord and its ependyma to evoke regeneration (Bellairs and Bryant, 1985). It also has been suggested that, in nonautotomous forms of lizards, extensive tail regeneration only occurs after tail loss involving damage to an actual vertebra and not as a consequence of the more common intervertebral separation (Etheridge, 1967).

The radiograph of the turtle tail described here suggests that the formation of the extra tail was caused by lateral damage to vertebrae: the outgrowths originate at the sides of vertebrae rather than at intervertebral spaces. This damage may have been the result of an injury caused by a bite to the

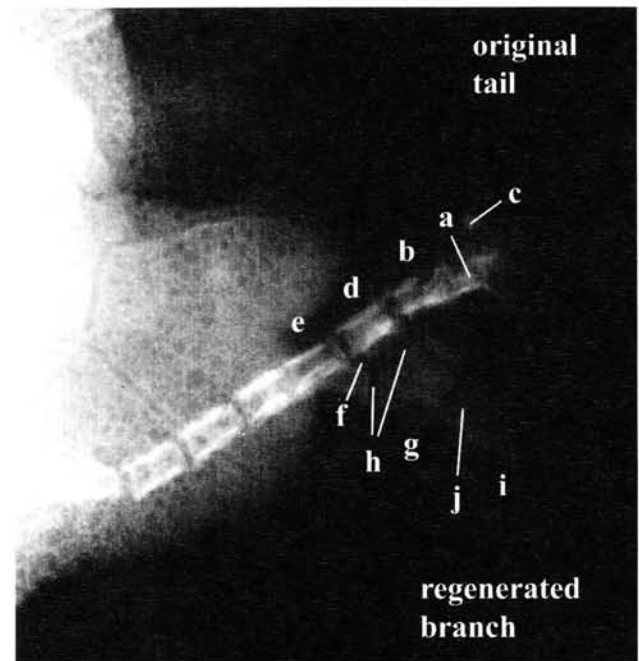


Figure 3. X-ray (ventral view) of the bifid tail of the adult male *Emydura* sp. The upper (left) branch is part of the original tail with ossified vertebrae, the lower (right) branch is formed of partially segmented cartilage or dense tissue. (a)–(j): see description in text.

tail, possibly inflicted by another turtle during aggressive interactions, or by a predator (crocodiles, for example, are common at the collection locality).

A general assumption of reptilian tail regeneration is that the skeleton of the regenerate is a cartilaginous tube or rod without segments and articulations. The regenerated muscles provide some mobility to the regenerated tail, although its flexibility is reduced. In some species the cartilage tube may become calcified or perhaps even ossified in mature, old regenerates, which may lead to complete rigidity (Bellairs and Bryant, 1985). A surprising finding is that the accessory tail regenerate of the turtle described here did not have a single elongated rod of cartilage as its skeleton, but rather an axis formed by several dense tissue segments that are separated by spaces reminiscent of intervertebral spaces. Even though these segments are wider and longer than the vertebrae of the original tail, the regenerating turtle tail may not grow a single tube or rod as skeleton, but produce several segments. After breakage or amputation of a regenerated lizard tail, the base of the new cartilage tube that subsequently forms is wider than the severed end of the old one (Bellairs and Bryant, 1985). The fact that some tissue segments in the present case are wider and longer than a typical turtle tail vertebra may reflect a similar relationship.

The shell of chelonians has considerable regenerative capacity (Kuchling, 1997). The bifid tail described here demonstrates that the tail of chelonians, too, has some regenerative capability. The results of this study suggest that further, more detailed investigations of tail regeneration in chelonians might reveal many features of interest.

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Thermoregulation in Captive Indian Ocean Giant Tortoises

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ABSTRACT. — Thermoregulation in captive Indian Ocean giant tortoises *Dipsochelys dussumieri*, *D. arnoldi*, and *D. hololissa* was investigated in the Seychelles, recording behaviors and temperatures. Cloacal temperatures were 27–33°C; moving into the shade or into water prevented this range being exceeded. Males of the saddle-backed form *D. arnoldi* exhibited basking behavior during the cooler months of the year; this is interpreted as a strategy to compensate for increased heat loss caused by carapace morphology.

Thermoregulation in ectothermic reptiles is a combination of physiological and behavioral adaptations to maintain body temperature within an optimum range or to adjust physiology when this is not possible (Avery, 1982; Huey, 1982). Behavioral thermoregulation takes the form of adjusting activity patterns to maximize heat uptake and avoid over-heating or chilling, through basking, aestivation, or hibernation (Bradshaw, 1986). Among chelonians basking occurs in many freshwater species (Sexton, 1959; Boyer, 1965; Ernst, 1972; Moll and Legler, 1971; Sajwaj and Lang, 2000) and some marine turtles (Boyer, 1965; Swimmer, 1997). It has only rarely been reported for terrestrial tortoises (occasionally in *Testudo* spp. and *Gopherus* spp.; Boyer, 1965). Avoidance of heat is recorded in many tortoises (*Chelonoidis nigra* [McKay, 1964, as *Geochelone elephantopus*]; *Gopherus* spp. [McGinnis and Voigt, 1971]; *Dipsochelys dussumieri* [Frazier, 1973, as *Geochelone gigantea*]) and aestivation in *Gopherus* tortoises (Voigt and Johnson, 1976). Deliberate orientation to minimize overheating occurs in all these taxa and probably occurs in all tortoise species.

The western Indian Ocean giant tortoises of the genus *Dipsochelys* are known to time active behavior to cool parts of the day, becoming less active with increasing temperature and using body orientation to minimize the risk of over-heating (Frazier, 1973). Furthermore, over-heating may be reduced by wallowing in water to cool the body (Lewis et al., 1992). All these observations are derived from Aldabran tortoises *D. dussumieri* (the nomenclature of this species remains contentious, the most frequent recent usage is followed here; other recent names are *Geochelone gigantea*, *D. elephantina*, and *Aldabrachelys gigantea*). Observations