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A tale of a wiggly tail: first osteological examination of the kinked-tail phenomenon in a wild-caught skink, *Sphenomorphus melanopogon* (Duméril & Bibron, 1839), from Timor-Leste

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Abstract. We provide a detailed description of "kinked-tail" malformation in a wild-caught skink, *Sphenomorphus melanopogon*, from Timor-Leste. While this type of vertebral pathology has been most frequently reported for terrarium-reared animals, it also exists in the wild. Regardless, there have not been any analyses of this condition that describe details of internal morphology. Malformations of caudal vertebrae in this individual included undulations in both frontal and sagittal planes, beginning at caudal vertebra 10 and continuing for ten successive vertebrae. We observed these malformations, to which the term kyphoscoliosis can be applied, almost exclusively in individual caudal vertebrae and rarely in the joints between them, revealing that the bones and not the intervertebral regions play the most important role in producing the kinked appearance. While we are unable to pinpoint the causes of the deformity, further detailed osteological studies of this phenomenon in captive and wild lizards may help to elucidate the condition and provide additional insights for clinical practitioners.

Keywords. Squamata, Scincidae, Lesser Sunda Archipelago, malformation, kyphoscoliosis, pathology

Introduction

'Kinked tail' is a term used in veterinary practice to describe the synonymous atypical tail morphology seen with considerable frequency in pet cats and dogs (Pollard et al., 2015; Paninárová et al., 2016), but also in wild and captive lizards and snakes (Ulber, 1986; Sant'Anna et al., 2013). Such malformations in squamates have primarily been reported in the herpetoculturist or veterinary literature (Wright, 2008), where malnutrition may lead to metabolic bone disease (MBD) and malformations or misalignments of the articulations between caudal vertebrae. Specifically, an improper balance of calcium and phosphorus in a captive animal's food, compounded by improper heating of a terrarium, has been cited as a primary cause of reptilian caudal malformations (Kaplan, 2001). The abnormality is often brought to light when lizards climbing on the netting at the top of an enclosure are observed to exhibit a hanging tail, and it appears that the mode of kinking in these cases is a gravity-driven single kink – 'tail buckling,' as reported for *Phelsuma* by Greckhamer (1995) – or a vertically aligned dorsoventral undulation. Ultimately, caudal tail deformations could result from misalignment or malformation of caudal vertebral elements or ligamentous laxity in intervertebral joints.

Most observations of squamate tail-kinking in the literature only briefly mention abnormalities, especially when encountered in hatchlings or juveniles during developmental studies. Such observations include those made for *Sceloporus undulatus* (Bosc & Daudin, 1801) by Angilletta et al. (2001), *S. jarrovii* Cope, 1875 by Beuchat (1988), *Amphibolurus muricatus* (White, 1790) by Harlow and Taylor (2000), *Lacerta agilis* Linnaeus, 1758 by Langford (1985), and *Heteronotia binoei* (Gray, 1845) by Kearney and Shine (2004). In these cases, the underlying causal factors of tail-kinking

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remained inconclusive. While tail-kinking may have an underlying genetic basis (Angilletta et al., 2001), such tail deformities have been observed repeatedly in a variety of reptiles when eggs are incubated at suboptimal or declining temperatures. Examples of this were reported for *Crocodylus novaeguineae*[5] Schmidt, 1928 and *Oedura monilis* De Vis, 1888 by Bustard (1969), *Python molurus* (Linnaeus, 1758) by Vinegar (1974), *Acritoscincus duperreyi* (Gray, 1839) by Shine (2004), *Crotaphytus collaris* (Say, 1822) by Louth and Heatley (2020), and *Timon lepidus* (Daudin, 1802) by Troidl (1997). While these studies provide valuable information on the prevalence, possible causal factors, and taxonomic breadth of the presence of tail-kinking, this phenomenon has only been reported in a developmental context for captive reptiles or their eggs.

Observations of kinked tails in wild squamate populations are not common and their causal mechanisms are generally not understood, although pesticides have been identified as one potential trigger (Garcês and Pires, 2023). As part of their recent report of kyphoscoliosis in a wild-caught skink, *Ctenotus fallens* Storr, 1974, Bateman et al. (2022) reviewed the literature and listed 19 species for which caudal vertebral deformations had been observed in the wild. We were able to locate several additional published accounts of reptiles in which this condition has been observed in the wild (Table 1). An investigation of body-kinking in a wild specimen of *Thamnophis radix haydeni* (Kennicott, 1860) concluded that it was injury-based, with the deformity occurring near a puncture wound to a vertebra that likely caused spinal cord damage and associated muscular dysfunction (termed “kypholordosis with scoliosis”; Smith and Fitzgerald, 1983). Following the reports by Garin-Barrio et al. (2011) and Avila et al. (2013), ours is the third report presenting x-rays of the condition, but it is the first to examine in detail the internal anatomy associated of caudal vertebral deformity, which we term kyphoscoliosis (i.e., comprising both curvature in both frontal and sagittal planes) in a wild lizard population.

During a comprehensive survey of the herpetofauna of Timor-Leste (Kaiser et al., 2011; O’Shea et al., 2012, 2015), the first author captured a skink of the genus *Sphenomorphus* (Fig. 1A) and was struck by the meandering shape of the tail. Unlike the descriptions of the kinked-tail phenomenon in the literature, this individual was from a wild population, and its tail appeared to be variably kinked when viewed in both dorsal (top-down) and lateral (side-to-side) aspects. Since the caudal morphology of this individual was incongruent with tail regrowth or incomplete tail autotomy, we resolved to explore the vertebral conformation of the tail in order to establish a baseline of morphological data for this type of tail-kink in a natural population. We report our findings herein.

Materials and Methods

Collection and initial processing. The individual was hand-captured during daylight hours on 4 February 2010 near the Meleotegi River, Eraulo, Ermera Municipality, Timor-Leste (8.7813°S, 125.4547°E; elevation 1222 m; Fig. 1B), during an active search of habitat bordering a riverbed (Fig. 1C). Specimen processing involved set photography using habitat materials in a 90-cm Cubelite (Lastolite, Coalville, Leicestershire, United Kingdom), humane euthanasia by intracardiac injection with a 5% procaine solution (Livezey, 1958), fixation and initial transportation in 10% formalin to the laboratory at Victor Valley College, and permanent storage in 70% ethanol. The specimen was subsequently deposited in the Division of Amphibians and Reptiles, National Museum of Natural History, Smithsonian Institution, Washington DC, USA (USNM), where it was accessioned as USNM 579234. Identification of the specimen as *S. melanopogon* follows the diagnosis and description provided by Shea (2012).

Imaging and data sources. The specimen’s tail was photographed and measured, and digital radiographs were obtained using a Kevex PXS5-724EA emitter and a Varian PanScan 4030R receiver (60-kV target tube voltage) at the Museum Support Center of the U.S. National Museum of Natural History, Smithsonian Institution, Suitland, Maryland, USA. X-rays were obtained in both dorsal and left lateral views. We use the terminology for caudal vertebrae of Etheridge (1967). Due to the unusual nature of the malformation and scarce data availability of comparative data, we utilized both literature and online sources to obtain reference materials. We also conducted an informal survey of several herpetologists, who we thought might have familiarity with both skeletal anatomy and tail-kinks.

[5] This species was divided into a southern and a northern species by Murray et al. (2019), with the populations south of New Guinea’s Central Cordillera now known as *C. halli*. Unfortunately, Bustard (1969) made no mention of his collecting locality, so it is not possible to determine to which of the two species this record refers.

Table 1. Instances of caudal malformations (the "kinked-tail" pathology) in squamates, as reported from husbandry (H) and wild (W) environments.

Taxon	Type	Source
LIZARDS		
Agamidae		
Agama anchietae Bocage, 1896	W	Grogan, 1976
Amphibolurus muricatus (White, 1790)	H	Harlow and Taylor, 2000
Calotes emma Gray, 1845	W	Ulber, 1986
Calotes versicolor (Daudin, 1802)	W	Datta and Hasan, 2020
Anolidae		
Anolis cybotes Cope, 1862	W	Tiburcio et al., 2021
Anolis sericeus Hallowell, 1856	W	Domínguez-De la Riva and Carbajal-Márquez, 2016
Chamaeleonidae		
Furcifer pardalis (Cuvier, 1829)	W	Gehring, 2009
Crotaphytidae		
Crotaphytus collaris (Say, 1822)	H	Louth and Heatley, 2020
Diplodactylidae		
Oedura monilis De Vis, 1888	H	Bustard, 1969
Gekkonidae		
Heteronotia binoei (Gray, 1845)	H	Kearney and Shine, 2004
Lepidodactylus lugubris (Duméril & Bibron, 1836)	W	Chan et al., 1984
Lygodactylus chobiensis Fitzsimons, 1932	W	Simbotwe, 1983
Phelsuma modesta leiogaster Mertens, 1973	W	Gehring et al., 2010
Iguanidae		
Amblyrhynchus cristatus Bell, 1825	W	Martínez-Castro and Sánchez-Vialas, 2023
Cyclura cychlura (Cuvier, 1829)	W	Owens and Knapp, 2007
Lacertidae		
Iberolacerta cyreni (Müller & Hellmich, 1937)	W	Horváth et al., 2021
Lacerta agilis Linnaeus, 1758	H	Langford, 1985; Idrisova, 2018; Gordeev et al., 2021
Podarcis pityusensis (Boscá, 1883)	W	Garin-Barrio et al., 2011
Timon lepidus (Daudin, 1802)	H	Troidl, 1997
Liolaemidae		
Liolaemus koslowskyi Etheridge, 1993	W	Avila et al., 2013
Phrynosomatidae		
Sceloporus formosus Wiegmann, 1834	W	Castillo-Juárez et al., 2020
Sceloporus grammicus Wiegmann, 1828	W	Hernández et al., 2024
Sceloporus jarrovii Cope, 1875	H	Beuchat, 1988
Sceloporus marmoratus Hallowell, 1852	W	Chávez-Cisneros and Lazcano, 2012
Sceloporus undulatus (Bosc & Daudin, 1801)	W	Mitchell and Georgel, 2005
Sceloporus undulatus (Bosc & Daudin, 1801)	H	Angilletta et al., 2001
Sceloporus vandenburgianus Cope, 1896	W	Valdez-Villavicencio et al., 2016
Scincidae		
Acritoscincus duperreyi (Gray, 1839)	H	Shine, 2004
Ctenotus fallens Stor, 1974	W	Bateman et al., 2022
Marisora brachypoda (Taylor, 1956)	W	Arrivillaga and Brown,2019
Sphenomorphus melanopogon (Duméril & Bibron, 1839)	W	this study
Teiidae		
Aspidoscelis marmoratus (Baird & Girard, 1852)	W	Rocha et al., 2023
Tropiduridae		
Stenocercus guentheri (Boulenger, 1885)	W	Ramírez-Jaramillo, 2018

Table 1. cont.

Taxon	Type	Source
SNAKES		
Colubridae		
Arizona elegans occidentalis Blanchard, 1924	W	Alvarez et al., 2021
Coronella austriaca Laurenti, 1768	W	Najbar et al., 2022
Natrix natrix (Linnaeus, 1758)	H	Idrisova, 2018
Thamnophis sirtalis (Linnaeus, 1758)	W	Gray et al., 2001, 2003
Pythonidae		
Python molurus[a] (Linnaeus, 1758)	H	Vinegar, 1974
Viperidae		
Bothrops ammodytoides Leybold, 1873	W	Feldman et al., 2025
Bothrops jaracara (Wied-Neuwied, 1824)	W	Sant'Anna et al., 2013
Crotalus durissus Linnaeus, 1758	W	Sant'Anna et al., 2013

[a] This abnormality may have been compounded by a hybrid parentage. Whereas the male of the kinked-tail embryo was a *P. m. molurus*, the female was a *P. bivittatus-P. molurus* hybrid.

Results

External anatomy. USNM 579234 (SVL = 54, TL = 101) was initially observed foraging in the leaf litter of a coffee forest, and its tail morphology did not appear to create any impediment to its movements. The tail exhibits five, primarily dorsoventrally oriented kinks (i.e., changes in direction) that impose upon the tail a wave-like external appearance (Figs. 1A, 2). No external puncture wounds or lacerations are visible at kink points in the tail, and there is no external appearance of tail breakage and regeneration in the tail area with kinks. There is an abrupt colour and scalation change in the tail immediately posterior to the kinked section, indicating that the distal portion of the tail is regenerated subsequent to a prior autotomic event. Tail-kinking commences 24 mm posterior to the cloacal opening and continues for 24 mm. The deformity is most severe (most acute angle on the inner curvature of the kink) near the tail base and at about the mid-point of the tail, with the distal (regenerated) half of the tail showing no evidence of kinking (Fig. 1A).

Osteology. The x-rays of USNM 579234 reveal 20 caudal vertebrae (CD), of which several show abnormalities. Four post-sacral, non-autotomic vertebrae with prominent transverse processes are followed by a series of elements with autotomy planes that have much smaller transverse processes, after which the tail terminates in a long, cartilaginous rod supporting the regenerated portion. The kinking begins at CD11 when viewed from the dorsal aspect (Fig. 3A, B) and at CD7 in lateral view (Fig. 3C) and continues to CD20. The regenerated tail portion begins posterior to the retained portion of CD21.

In dorsal view, the kinking first produces a slight rightward shift due to malformation of the joints on either end of CD11 (Fig. 3B). This is also the point where there is a significant dorsal bend in lateral view (Fig. 3C) that involves both CD11 and CD12. While CD13 occupies a level, horizontal position, CD14 appears to have undergone anteroposterior compression, which results in a much more vertical orientation in this view. The sinusoidal pathway followed by CD15–20, without any intense white areas in the radiograph (Fig. 3B), indicates that these two kinks lie entirely within the frontal plane. The lateral radiographic view (Fig. 3C) shows no longitudinal compression, with all vertebrae exhibiting similar white contrast. Two significant waves of kinking are apparent, with peaks at CD10 and CD15 and valleys at CD7 and CD12. A third directional change occurs at C18, where the vertebra shows a slight sigmoid curvature at each end. All caudal vertebrae appear to be of similar dimension (length, width, size of transverse processes), but there are intrinsic differences in how they are bent and displaced. Tail-kinks generally seem to result from extremely curved individual caudal vertebrae at the observed kinks in the tail, as opposed to intervertebral bending (i.e., deformation of joints between one or multiple bones). The exception may be the joint between C7 and C8 which appears to show some angulation.

The deformation of bones also produces a deformation of soft tissues, such as muscle. Kinking does not produce the usual, gradual and even decline in the width of spaces between external surfaces and the column of vertebral bodies. Instead, some dorsally much-narrowed spaces are produced, such as at C10 and C15, and a lateral narrowing occurs at C18.

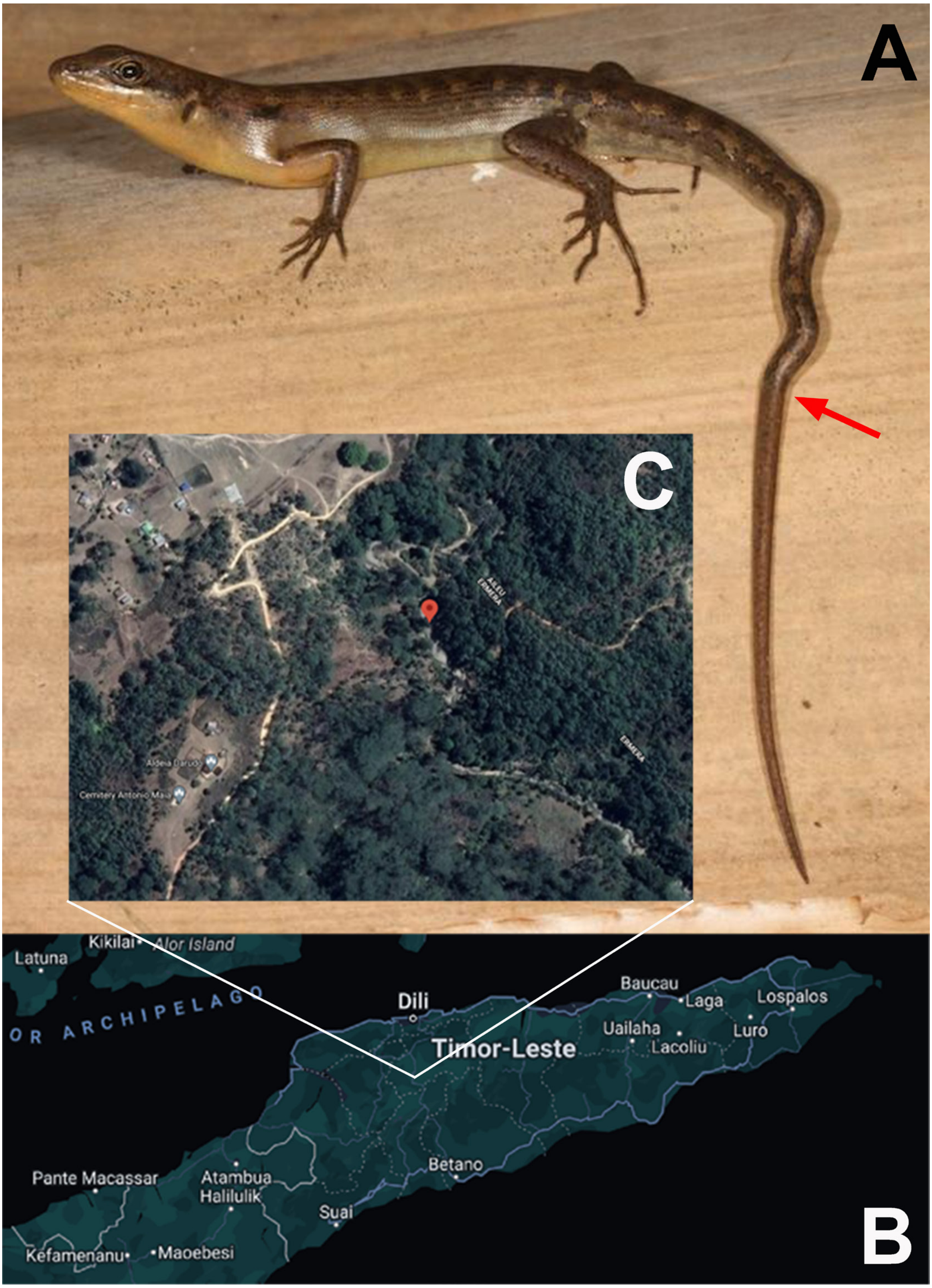

Figure 1. (A) A kink-tailed male *Sphenomorphus melanopogon* (USNM 579234) from Eraúlo, Ermera Municipality, Timor-Leste. The red arrow indicates where the regenerated tail begins. (B) Map of Timor-Leste showing the position of the collecting locality. (C) Satellite image showing the meandering course of the Meleotegi River, with coffee forest starting just below the red locator symbol.

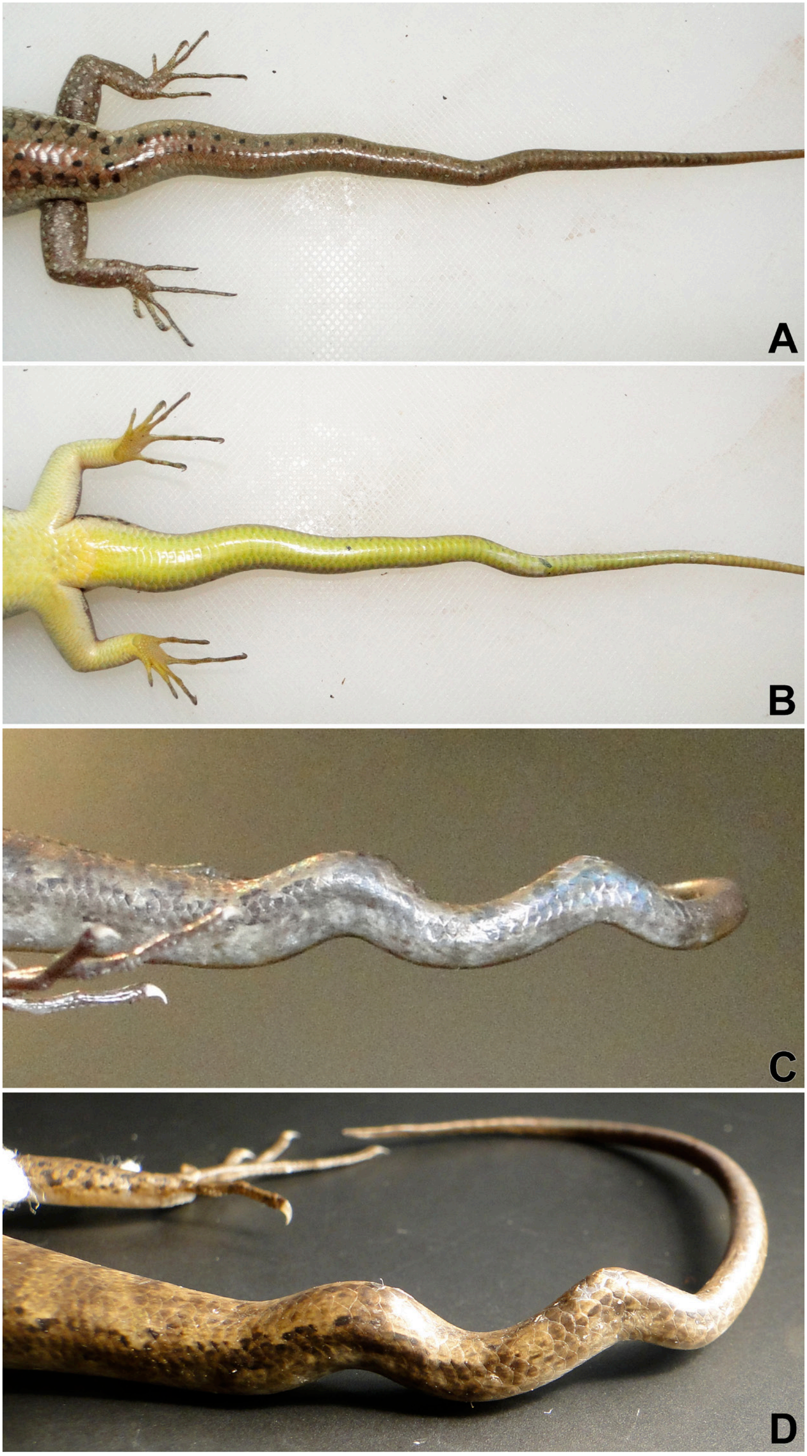

Figure 2. The kinked tail of a wild-caught *Sphenomorphus melanopogon* (USNM 579234) from Ermera Municipality, Timor-Leste, in (A) dorsal and (B) ventral views shortly after euthanasia. After fixation in standard "lizard position" with the tail curved to optimize storage, we took additional images in lateral (C) and dorsolateral (D) views to show that kinking exists in both frontal and sagittal planes around the tail's circumference.

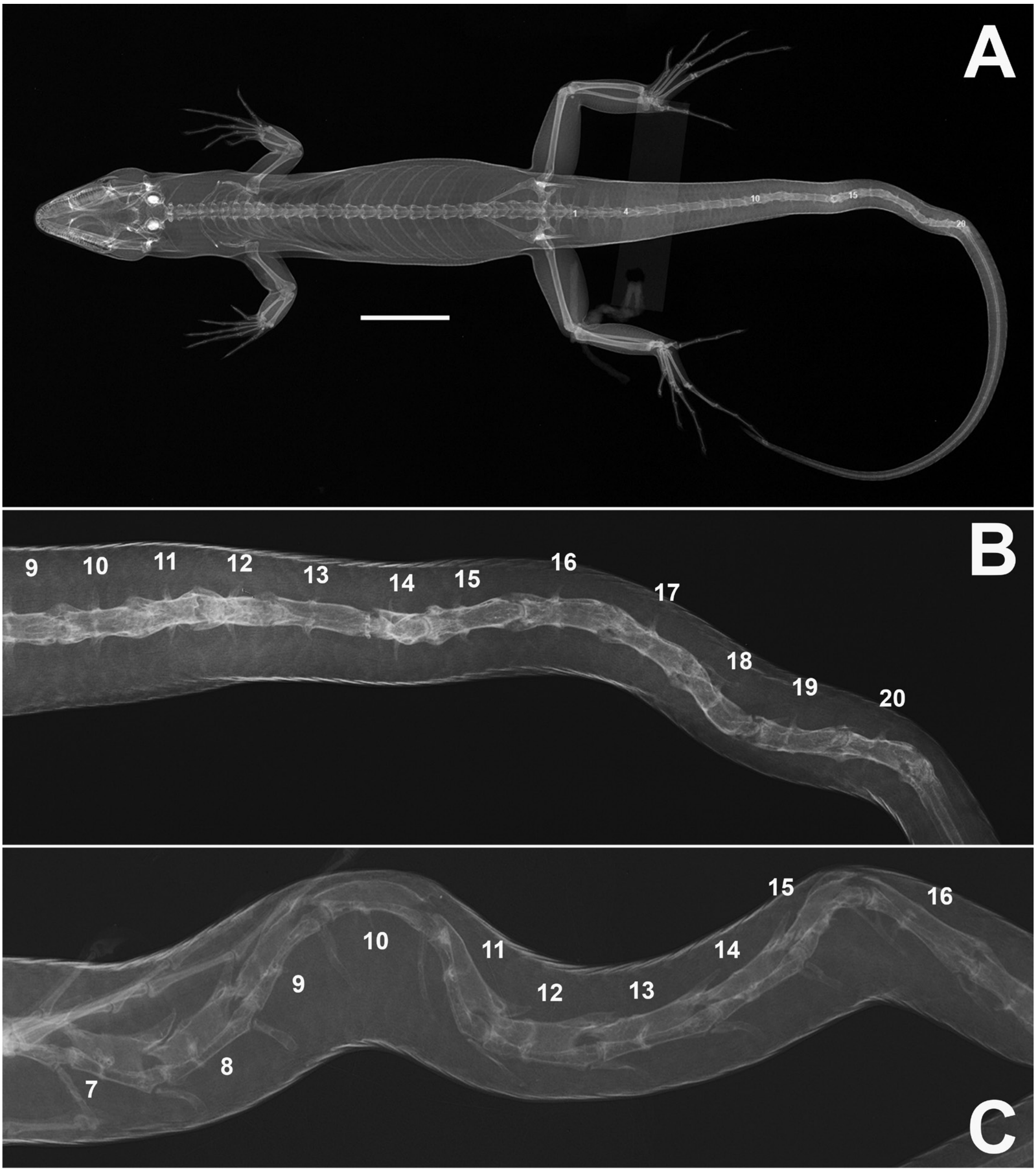

Figure 3. X-rays revealing the internal anatomy of the body and tail of a wild-caught *Sphenomorphus melanopogon* (USNM 579234) from Ermera Municipality, Timor-Leste. (A) The entire specimen in dorsal, whole-body view. (B) Dorsal view of the tail, showing caudal vertebrae numbered consecutively up to the point of tail regeneration. (C) Lateral view of the tail. Numbering of vertebrae corresponds to (B). Scale in (A) = 10 mm.

The reduction in musculature at these points is likely to affect the curvature of the tail, fixing the kinks in position.

Discussion

Our report is the first to describe aspects of the internal anatomy associated with tail-kinking in a wild lizard population. We are aware that this single observation and our limited analysis (especially when it comes to the potential for more detailed examination of bone and joint structure) are merely a departure point for future research. However, we felt that a basic report could lead to more advanced research approaches.

Based on external observations of kinked tails, the involvement of osteological abnormalities has naturally been suspected to underpin the morphology of kinking, but there have been no studies examining the specific internal morphology underlying tail-kinks. While we briefly report on this morphology here, we emphasize that this phenomenon may be more widespread in wild populations than previously thought.

Our observations show that the tail malformations in this lizard did not involve anterior, non-autotomic vertebrae but only autotomic vertebrae with single transverse processes (Etheridge, 1967). Given that the tail posterior to CD20 exhibits morphology consistent with regeneration (and therefore lacking vertebrae), it remains unknown whether any of the vertebrae lost at the autotomy event exhibited malformations associated with tail-kinking. While bone malformations would generally be considered disadvantageous in terms of natural selection, the level of kinking observed in this individual *S. melanopogon* did not appear to have any deleterious effects on the lizard, whose overall condition compared well with non-kinked specimens captured at the same site. Of course, it is unknown whether all individuals with kinked tails fare as well, or whether they succumb to their condition.

It has been suggested that in captivity, deficient diet and poor husbandry conditions (e.g., poor lighting, insufficient temperature, mineral deficiency) may lead to increased incidences of scale and skeletal malformations in both lizards and snakes (Vinegar, 1974; Shine, 2004; Kaplan, 2001; Idrisova, 2018; Louth and Heatley, 2020). However, how often deficiencies occur or how they influence tail development in wild populations is poorly understood or reported upon.

While kinked tails in wild populations have been observed in many types of lizards and snakes (Table 1), the causation and specific internal morphologies of these tail abnormalities were not resolved. Effects of temperature or humidity on the development of embryos in natural populations would require rigorous field experimental setup. Small population sizes leading to inbreeding have also been suspected as a cause of osteological deformities (Olsson et al., 1996). However, such abnormalities often resulted in early death; based on its size our specimen is an adult. Furthermore, population sizes are still unknown for most reptiles in Timor-Leste.

Curvature of the centra of individual caudal vertebrae, as in this case, suggests that their distortion may result from plastic bone response (Bouvier and Hylander, 1981; Russell et al., 1993), whereby the shape of a bone becomes altered over time, through bone remodelling, as a result of asymmetrical forces being imposed upon it. The eccentric placement of the vertebral column within the caudal tube that occurs at the sites of major bending (CD 9–11, 15–16, 17–19) could be an indication that the epaxial and hypaxial muscles are differentially developed on either side of the column. The implication of this would be that asymmetrical muscular forces are imposed upon the vertebrae in these regions, promoting distortion (curvature) of the centra. Given that vertebrae at critical locations in this lizard exhibit curvatures consistent with mechanical disturbances, potentially due to bone remodelling induced by asymmetrical loading on the centrum as a result of potential muscle atrophy at particular locations (the muscles are segmentally arranged), a future study should examine cross-sections of the tail to establish the relationship of the integument and muscles at malformed and "normal" stations along the tail.

Other hypotheses for the causes of tail-kinking include injury, mutations, parasitism, bacterial or fungal infections, or a lack of vitamins and minerals (e.g., hypovitaminosis A, calcium deficiency, phosphorous deficiency, MBD; Stahl, 2003). While not confirmed for lizards, mutations affecting the vertebrae of mice have been discovered (Hollander and Waggie, 1977), and mutations leading to spinal deformities in lizards may result in similar spine phenotypes. It is unclear whether any of these played a role in the tail-kinking observed in USNM 579234. Injury resulting from a predation attempt on this *Sphenomorphus* specimen cannot be ruled out, especially given the presence of a regenerated portion of the tail. It is likely that tail-kinking in wild populations is more prevalent than reported, and that this phenomenon exhibits significant variation in severity. Another aspect of tail malformation that has hitherto been considered unusual is tail furcation, which is now known to be observed in over 200 lizard species (Barr et al., 2020; Baum and Kaiser, 2024).

We believe that closer examination of museum specimens with tail deformities using x-rays, micro-CT scans, and histological examinations to enable a more complete 3D-appreciation of tail morphology, as exemplified by Gordeev et al. (2021), will be helpful in revealing the osteological details of tail-kinking more broadly. Closer examination of external and internal morphology of specimens that display kinked tails, particularly the twists and turns of bones and the role of joints in the condition, will likely help determine the causal factors of this phenomenon and its potential impacts on fitness, which should be welcome information for clinical practitioners of exotic pet medicine. Lastly, as indicated by Bateman et al. (2022), kyphoscoliosis may in some circumstances be a useful biomonitoring indicator of reptile susceptibility to pollutants or extremes in incubation temperature. At a time where human influences may poison habitats and perturb global temperatures, we encourage our readers to report additional examples of kyphosis and scoliosis in wild squamate populations.

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