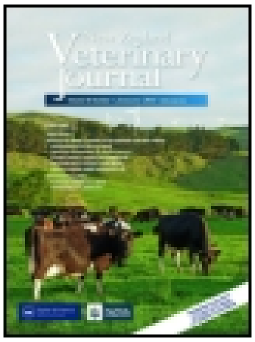

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CLINICAL COMMUNICATION

Thermal burns of the spectacle associated with supplementary heating in native New Zealand geckos

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ABSTRACT

Case history: Gradual onset of ocular opacity was observed in three gold-striped geckos (*Woodworthia chrysosiretica*), and five Pacific geckos (*Dactylocnemis pacificus*) held in two adjacent terrariums in a zoological institution located in the North Island of New Zealand. Ultraviolet light and heat had been provided for the previous 3–4 years by a fluorescent bulb, but in the last 4 weeks of winter a ceramic heat bulb had been added, situated 10 cm above the upper mesh of the cage

Clinical findings: All eight geckos presented with mostly bilateral lesions of varying severity confined to the central or upper quadrant of the spectacles. These lesions ranged from variable areas of opacity within the stroma of the spectacle to similarly distributed ulcers of the surface epithelium of both spectacles. The spectacle lesions in the Pacific geckos responded well to treatment with topical combined antimicrobial therapy, within 18–29 days. The gold-striped geckos suffered complications including dysecdysis, severe spectacle ulceration and perforation, mycotic spectaculitis, and widespread mycotic dermatitis resulting in death or leading to euthanasia.

Pathological findings: In the three gold-striped geckos, there were extensive areas of deep ulceration and replacement of the spectacle with a thick serocellular crust containing large numbers of fungal elements. The affected areas of the stroma were expanded by large deposits of proteinaceous and mucinous material, pyknotic cellular debris and moderate numbers of heterophils and macrophages as well as infiltrating fungal hyphae.

Diagnosis: Mycotic spectaculitis with ulceration and perforation, and disseminated mycotic dermatitis likely secondary to thermal burns.

Clinical relevance: This is the first report of thermal burns of the spectacle in any reptile. There was species variation in the burn severity with gold-striped geckos showing more severe lesions, possibly due to a mix of behavioural and anatomical factors. The thermal burns to the spectacles in three cases were complicated by delayed healing, perforation, dysecdysis and severe mycotic infection.

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KEYWORDS
Burn injury; brille; dysecdysis; Gekkota; mycotic dermatitis; spectacle ulcers

Introduction

Native New Zealand reptiles are often held by zoological institutions for public display and New Zealand geckos are one of the few species of native fauna that can be held under permit by private keepers in New Zealand. There has been considerable upheaval in the taxonomic classification of New Zealand reptiles and an expansion of the number of species recognised, including many cryptic species (Hitchmough *et al.* 2016b). In the wild, New Zealand gecko populations are generally declining, and are at risk from introduced predators, such as cats and rats, destruction of habitat and poaching for the international pet trade (Hitchmough *et al*. 2016a). The two species in this report, gold-striped geckos (*Woodworthia chrysosiretica*) and Pacific geckos (*Dactylocnemis pacificus*), have a conservation status of threatened, being considered as at-risk relicts (Hitchmough *et al.* 2016) and as such they are held by zoological facilities throughout New Zealand for advocacy purposes.

Geckos make extensive and subtle use of microclimate variations to meet their thermal, energetic and light requirements for physiological health and reproduction (Hitchcock and McBrayer 2006; Kearney and Predavec 2000). The terrariums that captive reptiles are held in do not always allow a full range of microclimate variations and sub-optimal husbandry can lead to serious health issues (Wilkinson 2015). Despite this, there is little scientific information on the detailed husbandry requirements of these animals. For example, the Department of Conservation best practice guide to keeping native reptiles is unreferenced and based exclusively on anecdote and the personal experiences of the author (Gibson 2016). While exact physiological parameters for these species have not been investigated, it has been suggested by experienced zoo keepers that they should be provided with temperature ranges of 15–25°C in summer, and 10–20°C in winter (Gibson 2016).

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The eyelids of geckos are fused to form a permanent immovable transparent membrane known as the spectacle (or brille). Beneath this membrane, the lacrimal fluid fills a shallow subspectacular space, draining through the nasolacrimal ducts. The cornea and deeper ocular structures lie beneath the spectacle and subspectacular space (Bellairs and Boyd, 1947). The epithelium of the spectacle is shed during moulting (ecdysis), but the stroma and subspectacular epithelium are not renewed in this process (Mead 1976). The vascularity of the stroma of the spectacle has been examined in Tokay geckos (*Gekko gecko*) and the vessels were found to be circumferentially oriented and reticulated (Mead 1976). Despite this vascularity, the spectacle is normally completely transparent. Previous reported conditions of the spectacle include trauma, mycotic and bacterial spectaculitis, retained spectacles during ecdysis, and pseudobuphthalmos (also known as bullous spectaculopathy) which is a distension of the subspectacular space due to lacrimal duct obstruction or inflammation (Lawton 2006).

Thermal burns are common in captive reptiles where supplementary heat sources are used, as these create focal areas of excessive heat within the terrarium (Hellebuyck *et al*. 2012). The lesions seen range from erythema to full thickness necrosis of skin, and the damaged areas of skin will often slough and become secondarily infected with opportunistic bacterial or fungal pathogens (Hellebuyck *et al*. 2012). It is not certain why such burns are so common, but recent nociceptive studies in reptiles using thermal stimuli show a marked variation in thermal response on different sites of the integument, and it may be that the dorsal skin of reptiles is less sensitive to thermal perception than the ventral surfaces of the feet and legs (Couture *et al*. 2017, Sladky *et al*. 2009). The thermal sensitivity of the spectacle has not been evaluated, to the best of our knowledge.

This clinical communication documents suspected thermal burns to the spectacles of eight native New Zealand geckos of two species, and charts the progression of the wounds, responses to treatment and secondary complications.

Case history

Mixed species of native geckos were held in two terrariums for public display in a zoological institution located in the North Island of New Zealand. They included three gold-striped geckos and five Pacific geckos in two adjacent enclosures. In the years 2016–2018, improper or incomplete shedding of the skin (dysecdysis) had been seen in some individuals, but this was largely resolved by reducing humidity in the enclosures. The terrariums were 1.5–2 m long × 1.2 m wide × 1.2 m tall with plants and grasses on the ground. Ultraviolet light and heat had been provided for the past 3–4 years by a fluorescent bulb (Osram, Munich, Germany) supplying 12 hours of light and 12 hours of dark per day. In the last 4 weeks of August 2018, a ceramic heat bulb (Trixie 100W, Tarp, Germany) had been added, situated 10 cm above the upper mesh of the cage which was left on 24 hours a day. The addition of the ceramic heat bulb was aimed at encouraging geckos to be more active over the winter. The gold-striped geckos were seen to stay higher in the enclosure on the mesh of the wall for basking than the Pacific geckos. Keepers noted a gradual onset of ocular opacity in all the geckos to varying extents within 2–3 weeks of the ceramic heat bulb being added to the enclosure. Temperature measurements within the enclosure revealed that directly under the ceramic heat bulb the mesh was reaching temperatures in excess of 50°C. All eight geckos were transported to Wildbase Hospital, (School of Veterinary Science, Massey University, Palmerston North, NZ) for assessment.

Clinical findings and treatment

All geckos of both species were in good body condition with no abnormalities other than the ocular findings. On close examination of the eyes under a dissecting microscope, all eight geckos had mostly bilateral lesions of varying severity confined to the central or upper quadrant of the spectacles (Figures 1 and 2; Table 1). These lesions ranged from variably sized, irregular-shaped, and in some cases, multifocal areas of opacity within the stroma of the spectacle, to ulcers of similar distribution within the surface epithelium of both spectacles. To reveal the presence and the full extent of any ulcers on the spectacle, one drop of fluorescein stain (Minims 1%, Bausch & Lomb, Macquarie Park, NSW, Australia) was applied to the spectacular surface. There was good uptake of the stain in the ulcerated areas of the spectacle similar to a corneal ulcer, but it took many days for the stain to dissipate. In all the geckos, the underlying subspectacular space, cornea and deeper ocular structures showed no visible abnormalities at presentation.

The geckos were initially treated with a topical application to the spectacles of a combination ointment containing polymixin B sulfate (10,000 IU/g), zinc bacitracin (500 IU/g) and neomycin sulfate (5 mg/g) (Tricin; Jurox, Auckland, NZ) four times daily. They were also given 0.2 mg/kg meloxicam (Metacam Oral Suspension for Cats, Boehringer Ingelheim, Manakau City, NZ) orally every 48 hours. For accurate dosing purposes, this was diluted 1:10 with normal saline. The geckos received supplementary feed once daily by offering a fruit pulp on a cotton tip applicator and encouraging the animals to lick this. They had access to fresh water, fruit pulp and an insectivore slurry (Grubs'n'Fruit; Repashy, Oceanside, CA, USA) on an *ad libitum* basis. The enclosures were sprayed once daily with fresh water to maintain relative humidity between 40–60% and a sphagnum moss-lined

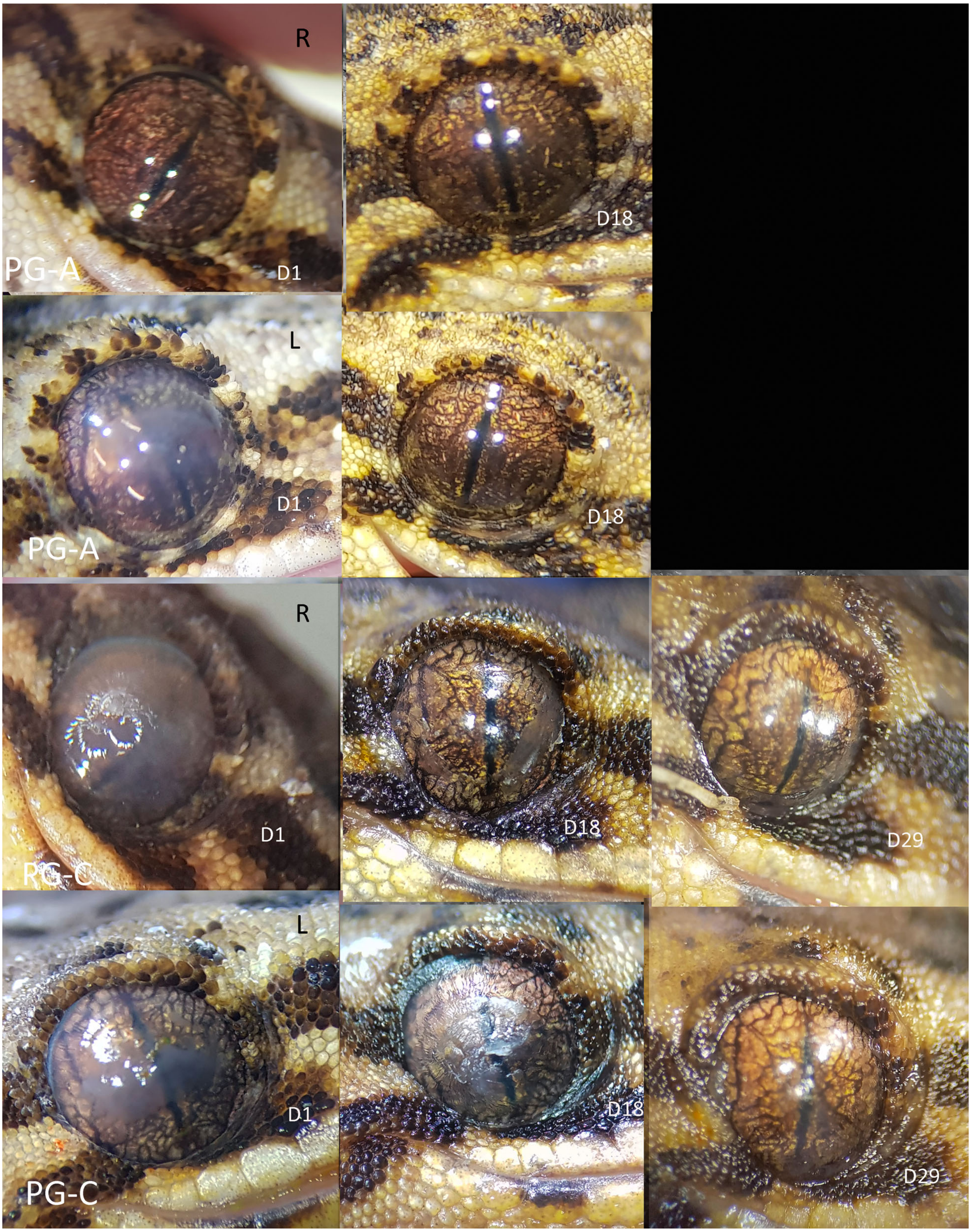

Figure 1. Photographs showing the changes in the spectacles of two Pacific geckos (*Dactylocnemis pacificus*) with suspected thermal burns. The top two rows show the right and left eyes, respectively, of one gecko (PG-A) on days 1 and 18 after hospitalisation, and the third and fourth rows show the right and left eyes, respectively, of another gecko (PG-C) on days 1, 18 and 29. All images were taken through a dissecting microscope; the white highlights on the spectacle are reflections of the light sources.

wet box was provided. The geckos were initially housed in two glass terrariums grouped by species, but from day 12 of hospitalisation onwards were placed in individual terrariums to reduce the potential for opportunistic pathogen transfer between animals. Ultraviolet light was provided by a fluorescent lamp supplying 12 hours of light and 12 hours of dark per day and the temperature of the room was controlled between 16–22°C.

The spectacles of the five Pacific geckos responded well to this treatment. The stromal opacities cleared over 18 days and three of these geckos were discharged at this time (Figure 1; Table 1). Two of the Pacific geckos

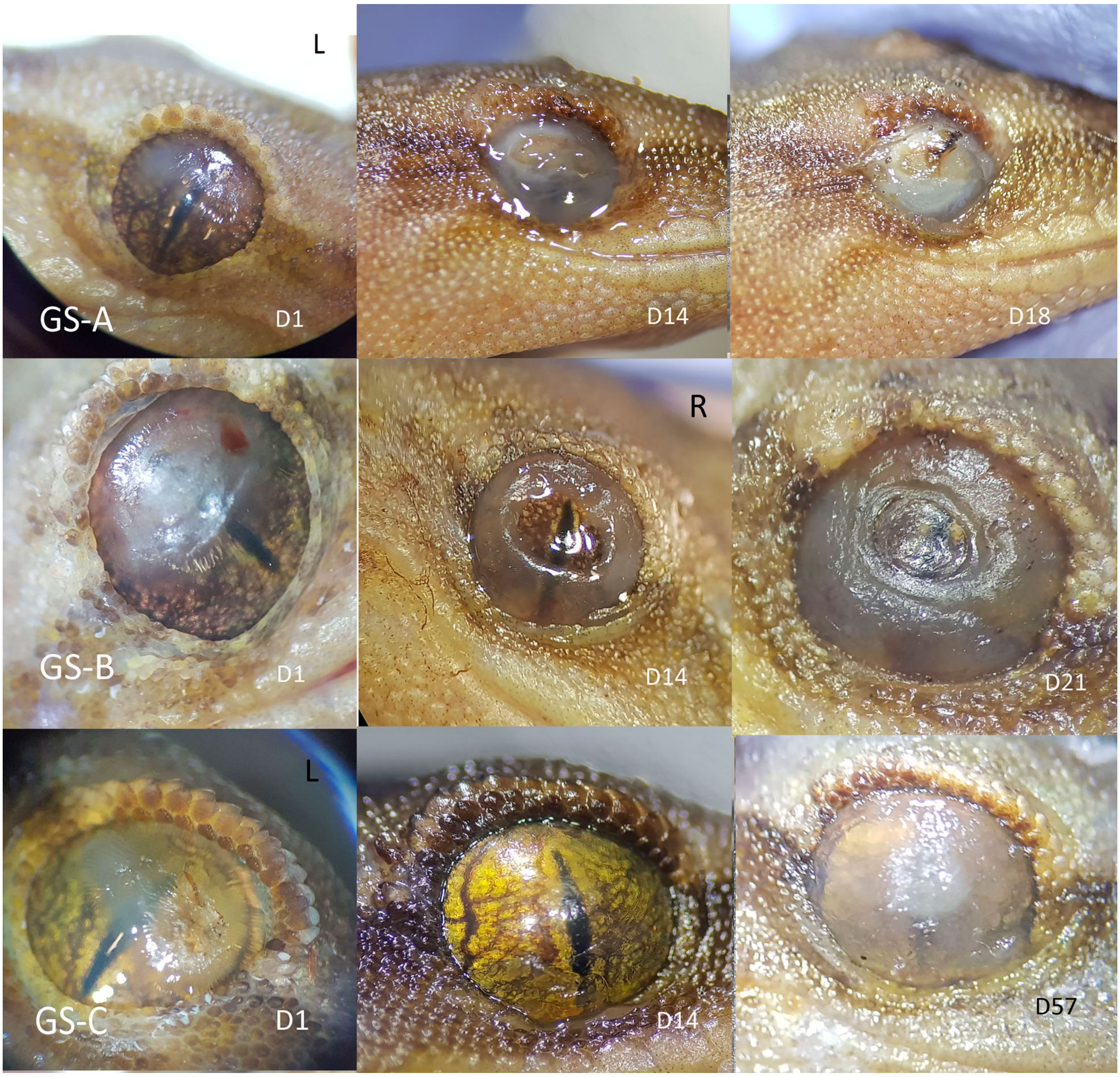

Figure 2. Photographs showing the changes in the spectacles of three gold-striped geckos (*Woodworthia chrysosiretica*) with suspected thermal burns. The top row shows the left eye of one gecko (GS-A) on days 1, 14 and 18 after hospitalisation, showing collapse of the subspectacular space. The second row shows the right eye of gecko GS-B on days 1, 14 and 21, showing perforation of the spectacle on day 14 and subsequent healing and contraction of spectacle stroma on day 21. The third row shows the left eye of gecko GS-C on days 1, 14 and 57, showing initial improvement on day 14, but subsequent deterioration on day 57. All images were taken through a dissecting microscope; the white highlights on the spectacle are reflections of the light sources.

developed dysecdysis with retention of shed skin on distal limbs and in the axillary region. One with bilateral spectacle ulcers (PG-C) also retained the damaged left spectacle during ecdysis. Dysecdysis was resolved by soaking these two geckos in warm water for 15 minutes twice daily until the softened retained skin and spectacle were shed and they were discharged after 22 and 29 days of hospitalisation (Figure 1).

The three gold-striped geckos responded less well to treatment (Figure 2; Table 1). The first (GS-A) showed mucoid exudate over the spectacles and developed a white dermal nodule (~1 mm^2) on its elbow on day 12 of hospitalisation. Similar white nodules first appeared on another gold-striped gecko (GS-C) on day 18 of hospitalisation. Scrapings of these lesions were stained with modified Wrights stain (Diff-Quik) and macrophages, heterophils and occasional fungal hyphae were detected. Bacterial and fungal cultures of a swab from this area were carried out by a commercial diagnostic laboratory (NZVP, Palmerston North, NZ) but no organisms were cultured. On the basis of the cytology and progression of dermal and spectacle lesions, the three gold-striped geckos were moved into individual terrariums and treated with 10 mg/kg compounded oral voriconazole (Optimus Healthcare Compounding Pharmacy, Auckland, NZ) orally once daily and 20 mg/kg ceftazidime (Ceftazidime; Mylan, Auckland, NZ) I/M every 72 hours. Dermal lesions were gently debrided with chlorhexidine and topical miconazole nitrate (Miconazole Cream, Pharmacy Medicine, Auckland,

Table 1. Summary of clinical findings, duration of hospitalisation, complications and outcome for five Pacific geckos (*Dactylocnemis pacificus*) and three gold-stripe geckos (*Woodworthia chrysosiretica*) with suspected thermal burns to the spectacles.

Gecko	Initial findings: Right spectacle	Initial findings: Left spectacle	Hospitalisation (days)	Complications	Outcome
Pacific geckos					
PG-A	No significant findings	Central stromal opacity	18	None	Discharged
PG-B	No significant findings	Upper quadrant stromal opacity	18	None	Discharged
PG-C	Diffuse stromal opacity, central ulcer	Central stromal opacity, central ulcer	29	Dysecdysis. Retained left spectacle	Discharged
PG-D	Bilateral upper central stromal opacity		22	Dysecdysis	Discharged
PG-E	Fine stromal opacity in central caudal region	Diffuse patchy white stromal opacities	18	None	Discharged
Gold-stripe geckos					
GS-A	Upper quadrant spectacle ulcer	Stromal opacity and irregular spectacle surface	18	Disseminated mycotic dermatitis. Unilateral mycotic spectaculitis (left)	Euthanasia
GS-B	Upper quadrant spectacle ulcer, with focal haemorrhage	Spectacle ulcer, cloudy stroma	121	Bilateral spectaculitis. Disseminated mycotic dermatitis. Dysecdysis	Died
GS-C	Upper spectacle ulcer and distortion	Upper spectacle ulcer and distortion, stromal opacity	72	Disseminated mycotic dermatitis. Bilateral mycotic spectaculitis	Euthanasia

NZ) was applied once daily. By day 18, one of the geckos (GS-A) was deteriorating in activity, alertness and appetite, and the clinical appearance of the spectacle (Figure 3), and was subjected to euthanasia using 5 mg/kg I/M alfaxalone (Alfaxan; Jurox, Auckland, NZ) followed by ~100 mg/kg intracardiac sodium pentobarbitone.

The spectacle lesions and periorbital swelling in remaining gold-striped geckos (GS-B and GS-C) resolved and then regressed. In one (GS-B) isolated white dermal nodules (~1–2mm^2; 0–3 at a time) appeared then resolve in different parts of the dorsal skin over a period of 6 weeks.

On two separate occasions, each gecko was sedated with 5 mg/kg I/M morphine (Morphine Sulfate; Biomed, Auckland, NZ) and anaesthetised with inhaled isoflurane in oxygen via a mask. Under magnification with a dissecting microscope, the necrotic eschar of material on the spectacles was gently debrided from the spectacle using the tip of a 23 gauge needle. This left an open perforation in the spectacle that communicated with the subspectacular space, exposing lacrimal fluid and the cornea (Figure 2). The wound was then irrigated with normal saline, and treatment continued as before. The spectacle perforations healed slowly with an initial closing of the basement membrane of the spectacle, followed by contraction and healing of the stroma (Figure 2), with the epithelium of the spectacle being the last to close. While the corneas were exposed, the eyes were monitored closely, but showed no evidence of keratoconjunctivitis sicca during this period, and the underlying cornea, aqueous chamber and iris remained visibly normal.

At day 45 of hospitalisation, the spectacle and dermal lesions were proving refractory to treatment, so the medication plan for both remaining geckos in hospital was reassessed. The topical combination ointment was changed to a topical chloramphenicol ointment (Chlorsig; Pharmacy Retailing, Auckland, NZ) four times daily, and the dosing frequency of voriconazole was increased to 10 mg/kg orally twice daily, while meloxicam (0.2 mg/kg orally every 48 hours) and ceftazidine (20 mg/kg I/M every 72 hours) were continued unchanged. There was initially a positive response to this change of medication, with a resolution of dermal nodules at the next period of ecdysis and a reduction in periorbital swelling and spectacle lesion severity. However, by day 72 of hospitalisation one gecko (GS-C) showed severe sloughing of the spectacle of both eyes and this animal was subjected to euthanasia. The third gecko (GS-B) required several further debridements of the spectacles and chemical debridement of the spectacles was instituted using dilute povidone iodine on three occasions. The dermatitis elsewhere on the body initially resolved well with the change of medications, however around day 110 of hospitalisation the dermatitis returned and was refractory to treatment. The gecko remained bright, active and was feeding well despite the continued dermatitis until day 121 when it deteriorated quickly and died.

Pathological findings

Post-mortem findings were similar for the three gold-striped geckos. There were grey dermal nodules and black crusty exudative skin lesions over the shoulder region, with opacity and ulceration of the spectacles. There were areas of retained shed skin over the dorsal thorax, ventral abdomen, pelvis and hind digits of one gecko (GS-B). Histologically there was extensive deep ulcerative periocular dermatitis (Figure 3). There was replacement of the spectacle with a thick serocellular crust containing large numbers of fungal spores

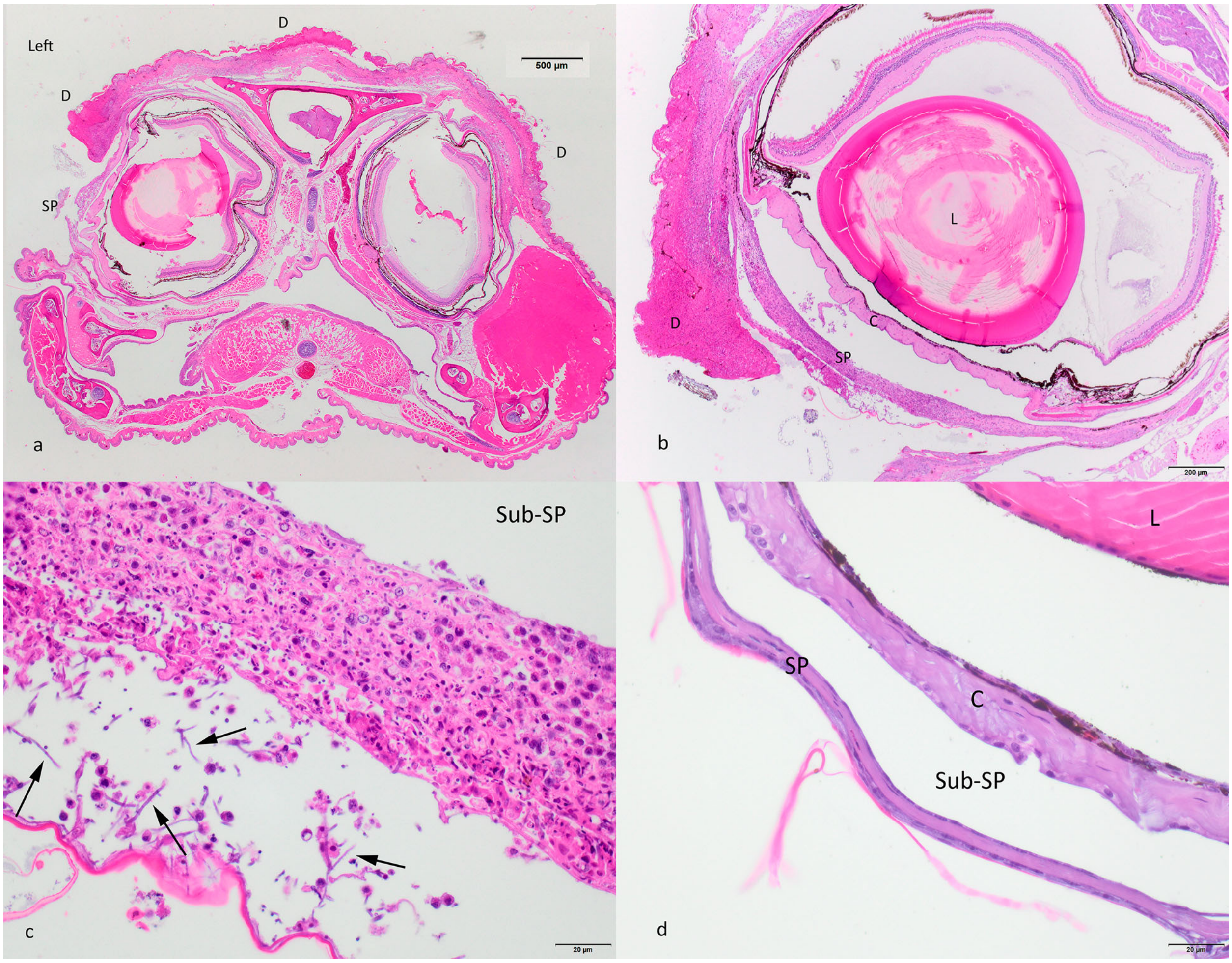

Figure 3. Photomicrographs of sections of (a) the head of one gold-striped gecko (*Woodworthia chrysosiretica*) (GS-A) showing patches of dermatitis (D) and severe spectacle inflammation and ulceration (SP) (bar = 500 μm); (b) the left eye from the same animal showing the normal lens (L), cornea (C), severe spectacle inflammation and ulceration (SP), and periocular dermatitis (D) (bar = 200 μm); (c) the spectacle from the same animal showing extensive infiltration of the stroma with mixed heterophils, macrophages and numerous fungal hyphae (arrows) (bar = 20 μm); (d) the eye of a normal gold-stripe gecko showing the lens (L), cornea (C), subspectacular space (Sub-SP) and spectacle (SP) (bar = 20 μm). All sections stained with H&E.

and hyphae. The subjacent stroma was expanded by large deposits of proteinaceous and mucinous material, pyknotic debris and moderate numbers of heterophils and macrophages, as well as infiltrating fungal hyphae. The adjacent intact epidermis was moderately hyperplastic with swollen keratinocytes as well as heterophilic transcytosis, most likely as a reaction to adjacent infection. The black crusty lesions noted grossly were composed of areas of mild epidermal hyperplasia and hyperkeratosis associated with superficial clusters of pigmented fungal hyphae, and small numbers of heterophils were visible within the epidermis. The pathological diagnosis in all three animals was mycotic spectaculitis and dermatitis.

Discussion

In the eight geckos described here, the spectacle lesions were confined to the upper quadrant of the eye, and the synchronous appearance of the spectacle lesions was coincident with the recent placement of ceramic heat bulbs in the terrariums. Zookeepers also reported that the mesh on the roof of the terrariums was reaching temperatures in excess of 50°C. Our clinical and pathological investigation revealed mycotic spectaculitis with ulceration and perforation, and disseminated mycotic dermatitis, likely secondary to thermal burns as the initiating cause of the spectaculitis. To the best of the authors' knowledge, this is the first report of thermal burns of the spectacle in any reptile. Furthermore, this report is the first demonstration that fluorescein staining is useful in delineating the presence and extent of ulceration of the surface epithelium of the spectacle. The thermal burns in these cases were complicated by adherence of necrotic debris, delayed healing and severe local and disseminated mycotic dermatitis.

The anatomy of the spectacle creates some therapeutic challenges in the treatment of superficial ulcers. In a corneal ulcer, the lacrimal fluid provides a mix of aqueous and mucinous lubrication, and a variety of protective mechanisms against infection including secretory immunoglobulins, lysozymes and lactoferrin (Kautto *et al*. 2016). It also means that systemic medications can be used to bathe the surface of the eye via lacrimal fluid transport (Monk *et al*. 2018). For geckos, the lacrimal fluid is confined within the subspectacular space, therefore we postulate that, compared to a corneal ulcer, surface ulceration of the spectacle is more prone to desiccation, adherence of necrotic exudates and secondary infection. The healthy spectacle is composed of β-keratin and its surface is hydrophobic, reducing the adherence of dust and fluid to its surface, which is regularly cleaned by tongue flicking (Cooper *et al*. 1996; Autumn and Hansen 2006). We postulate that when the epithelium of the spectacle is ulcerated hydrophobicity is lost, and tongue flicking is unlikely to be effective in cleaning the ulcered surface, resulting in contamination of lesions with oral microbiota and food debris. Further, attempts to clean the spectacle with tongue flicking may remove topical medications and result in their ingestion.

From the initial appearance of the spectacle lesions, we suggest that the heat first caused damage to the stroma, before the more resilient keratin of the spectacle was damaged. In four of five Pacific geckos, the initial lesions were confined to visible stromal opacity, while the keratinised epithelium of the spectacle was intact. These lesions resolved quickly and without complications, which suggests a good prognosis if thermal burns of this area can be detected when only stromal lesions are present. In these cases, there was no evidence of acute cellular inflammatory responses or erythema within the stroma of the spectacle, but the changes seen may have been consistent with oedema, protein and cell exudation.

The susceptibility of the reptile spectacle to thermal injury may be related to the transparent nature of the spectacle absorbing more heat than opaque pigmented skin. The cornea of mammals and humans is protected by the thermal diffusivity of the lacrimal fluid (van Gemert *et al*. 2018), but the transparent spectacle lacks this layer, potentially meaning thermal radiation is transmitted directly into the stroma.

The frequency of complications was much higher, and outcomes were worse, in gold-striped geckos than the Pacific geckos. This may have been simply due to the burns in the Pacific geckos being less severe, as keepers noted that they basked further away from the heat lamps than the gold-striped geckos. Alternatively we speculate that, as nocturnally active geckos, the spectacle of the gold-striped geckos may be thinner and more prone to thermal injury. However, even nocturnal geckos need to emerge into direct sunlight for basking and thermoregulation (Gibson *et al*. 2015). More research is needed to understand the comparative anatomy and physiology of the spectacle between species, as currently all our knowledge of the spectacle is based on cross-species extrapolations.

All three gold-striped geckos suffered mycotic dermatitis as a complication of the initial thermal injury. However, mycotic dermatitis is also common in reptiles associated with incorrect husbandry conditions such as temperature and humidity (Hellebuyck *et al*. 2012). While the geckos were in hospital, the temperature range was maintained between 16–22°C and the relative humidity between 40–60%. It is possible that this humidity was too low and contributed to the development of the mycotic dermatitis. A humidity range of 60–70% has been recommended for all native gecko species (Gibson 2016), but it is unclear what this recommendation is based on. It is very likely that different species of geckos have differing husbandry requirements, which can in turn affect the skin microbiota and patterns of ecdysis, sometimes resulting in dermatitis (Gartrell and Hare 2005). More research is needed to provide evidence-based recommendations for the husbandry of the native New Zealand herpetofauna.

Treatment and diagnostic options in these geckos were limited by their small size. The Pacific geckos ranged between 11–13 g in bodyweight, and the gold-striped geckos were between 6–8 g. The use of a dissecting microscope greatly aided visual appraisal of the lesions and surgical debridement. The small size of these patients also made accurate dosing challenging. Initially, the geckos were dosed with oral medications by putting droplets of medication on their lips and waiting for them to lick these off. However, the mycotic dermatitis showed a marked clinical improvement when direct oral dosing using a 24 gauge soft catheter tip was instituted. The doses of medications used were extrapolated from doses used in other reptiles (Carpenter and Marion 2017), and a clinical improvement in response to voriconazole was noted when dosing frequency was increased from once daily. It is possible that the metabolism of drugs in these small reptiles is very different from the species used to establish these doses, such as turtles (Giorgi *et al*. 2015) and bearded dragons (Couture *et al*. 2017). However, given the small size of this species, pharmacokinetic studies are unlikely to be able to be performed with the current technology available.

In conclusion, this clinical communication illustrates an unusual presentation of thermal burns in native New Zealand geckos. While thermal burns are commonly recognised in captive reptiles, this is the first report of this injury to the spectacle. The progression and complications encountered in the management of this case highlights the limits of our knowledge of the response of the spectacle to injury and the challenges associated with the small size of these patients and cross-species extrapolations needed to apply veterinary care. Furthermore, these injuries show the importance of further research to inform husbandry guidelines that meet species-specific needs of native New Zealand herpetofauna.

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