RADIOGRAPHIC ANATOMY AND BARIUM SULFATE CONTRAST TRANSIT TIME OF THE GASTROINTESTINAL TRACT OF BEARDED DRAGONS (*Pogona vitticeps*)

CLAIRE GROSSET, LISE DANIAUX, DAVID SANCHEZ-MIGALLON GUZMAN, ERNEST SCOTT WEBER III, ALLISON ZWINGENBERGER, JOANNE PAUL-MURPHY

The positive contrast gastrointestinal study is a common non-invasive diagnostic technique that does not require anesthesia and enables good visualization of the digestive tract. Radiographic anatomy and reference intervals for gastrointestinal contrast transit time in inland bearded dragons (*Pogona vitticeps*) were established using seven animals administered 15 ml/kg of a 35% w/v suspension of barium by esophageal gavage. Dorso-ventral and lateral radiographic views were performed at 0, 15, 30 min, 1, 2, 4, 6, 8, 12 h, and then every 12 h up to 96 h after barium administration. Gastric emptying was complete at a median time of 10 h (range 4–24 h). Median jejunum and small intestinal emptying times were 1 h (range 30 min–2 h) and 29 h (range 24–48 h), respectively. Median transit time for cecum was 10 h (range 8–12 h). Median time for contrast to reach the colon was 31 h (range 12–72 h) after administration. Results were compared to those obtained in other reptilian species. This technique appeared safe in fasted bearded dragons and would be clinically applicable in other lizard species.

Key words: bearded dragon (*Pogona vitticeps*), barium, contrast, gastrointestinal transit time.

Introduction

INLAND BEARDED DRAGONS (*Pogona vitticeps*) are reptiles commonly kept as companion animals in North America, Australia, and Europe.[1] Approximately 500,000 juvenile bearded dragons are produced annually in the United States.[2] Gastrointestinal disorders are a common clinical presentation in bearded dragons often associated with several clinical signs including anorexia. Causes are various and include phytobezoars secondary to dehydration,[3] obstruction by foreign bodies secondary to substrate ingestion,[4] parasites,[3] and neuroendocrine gastric carcinoma.[5,6] Ileus or constipation can also be secondary to anatomic malformation of the pelvis or spine,[3] follicular stasis, renomegaly, or other organomegaly.[3] Contrast studies offer a noninvasive technique to investigate gastrointestinal transit in reptiles, as previously described in green iguanas (*Iguana iguana*),[7] ball pythons (*Python regius*),[8] leopard tortoises (*Testudo pardalis*),[9] Mediterranean tortoises (*Testudo hermanni*),[10] hawsbill sea turtles (*Erethmochelys imbricata*),[11] loggerhead sea turtles (*Caretta caretta*),[12] and red-eared slider turtles (*Trachemys scripta elegans*).[13] Digestive emptying times are typically higher in reptiles compared to mammals,[12–14] and this transit time may increase with gastrointestinal disease: up to 40 days has been reported in loggerhead sea turtles.[12] Gastrointestinal anatomy and normal digestive transit of barium has not been evaluated in healthy bearded dragons.

The aims of this study were to evaluate contrast transit time, to describe the normal anatomy of the bearded dragon gastrointestinal tract, and to evaluate possible adverse effects of barium administration to bearded dragons.

Materials and Methods

Seven bearded dragons and four bearded dragon cadavers obtained from a private breeder were used to investigate the anatomy and imaging characteristics of the gastrointestinal tract. This project was approved by the Institutional Animal Care and Use Committee of the University of California, Davis.

Four adult bearded dragons, two females and two males (weight range 150–282 gm), were used to establish the normal gross anatomic structures and topography of the gastrointestinal tract. Three of these bearded dragons were preserved in 10% formalin solution after being used in another experimental study, and had no digestive lesions. One of the four bearded dragons was an adult male euthanized due to congestive heart failure. Post mortem, the digestive

William R. Pritchard Veterinary Medical Teaching Hospital (Grosset, Daniaux) the Departments of Medicine and Epidemiology (Guzman, Weber, Paul-Murphy) Surgical and Radiologic Sciences (Zwingenberger) School of Veterinary Medicine, University of California, Davis, CA 95616.

Address correspondence and reprint requests to Joanne Paul-Murphy at the above address. E-mail: paulmurphy@ucdavis.edu

Received July 2, 2013; accepted for publication September 29, 2013.
doi: 10.1111/vru.12128

tract was sutured at the level of the cardia and the cloaca, and barium contrast was injected into the stomach with a 20 gauge needle (Monoject, Tyco Heathcare Group LP, Mansfield, MA) mounted on a 20 ml syringe. The digestive tract was dissected and isolated from the body, and a radiographic view was obtained to determine the radiographic appearance of the lumen of the gastrointestinal tract.

Seven adult captive-bred bearded dragons, three females and four males (weight range 150–297 gm), were obtained from a private breeder (Sandfire Dragon Ranch, Bansall, CA). Prior to this study animals were used to teach handling and diagnostic techniques to veterinary students and were housed individually in aquaria equipped with full-spectrum fluorescent lights (Desert 50 UV B fluorescent bulb, Zilla 20W, Franklin, WI) set on a twelve hr daily cycle, with an infrared lamp (Zilla 50W, 120V, Franklin, WI. Roche Cobas C501 Chemistry Analyzer, Roche Diagnostics, Indianapolis, IN) providing a temperature gradient ranging from 28°C to 31°C. The diet consisted of dark leafy greens, crickets (*Acheta domesticus*), and mealworms (*Tenebrio molitor*). Physical examinations were conducted for each animal and a 1 ml blood sample was obtained from the ventral coccygeal vein with a 25 gauge needle mounted on a 1 ml syringe. Physical examination, hematocrit (Hematocrit tube, Fisherman scientific, Pittsburgh, PA), biochemistry panel, and fecal parasitic examinations by fecal flotation (Zinc sulfate 7-hydrate, Ovassay, Symbiotics Corporation, Pfizer Animal Health, New York City, NY) were unremarkable and all the animals were considered healthy when enrolled in the study.

The day prior to administration of barium contrast, bearded dragons were moved to a room adjacent to the radiology equipment to minimize environmental temperature fluctuations during the study and decrease stress that may be associated with transport. Ambient room temperature was maintained between 28°C and 33°C and temperature was recorded in each terrarium to insure homogeneity of the environmental temperature between 28°C and 33°C. Animals were housed individually in glass terraria (120 cm × 35 cm × 35 cm) without physical nor visual contact between subjects. The aquarium substrate was newspapers, changed daily unless more frequently required. Full-spectrum fluorescent lights (Repti Glo 10.0, Hagen Inc., Mansfield, MA) were provided, 13 h/day at a distance of 30 cm from the animals.

Each animal was fasted and water was withdrawn 10 h prior to barium administration. Survey radiographs were taken 10 h before barium administration and no radiographic abnormalities were identified. Three mls of barium 105% w/v suspension (Barium sulfate, E-Z-EM Canada Inc, Lake Success, NY) were diluted with six milliliters of tap water to obtain a 35% w/v thoroughly homogenized suspension. Barium was administered to each lizard (15 ml/kg) into the thoracic esophagus using a 10-gauge, 15 cm (6-inch) long stainless steel blunt-tipped feeding tube inserted to the level of the sternal xiphoid process. Each lizard was held vertically with the head up during the administration of the barium, and maintained in this position for an additional 30 s postbarium administration. Radiographs were taken immediately after barium administration, then 15, 30 min, 1, 2, 4, 6, 8, 12, 24, 36, 48, 60, 72, 84, and 96 h after contrast administration. Radiograph times were determined based on a pilot study performed in one bearded dragon not included in the study. Exposure settings were 54 kV, 160 ms and 5 mAs, with a standard focus-film distance of 109 cm on the X-ray machine (X-ray Generator, Sedecal model SHF-310, Sedecal, Buffalo Grove, IL; X-ray Tube, Toshiba Rotanode model E7239X, Toshiba America Information System Inc., Irvine, CA; Console Global, Sedecal model A-6199–01, Sedecal, Buffalo Grove, IL). Each bearded dragon was positioned with the pelvic limbs extended caudally and restrained along the tail with bandaging material (Red Cross Secure-Comfort Cloth Tape, Johnson&Johnson, Skillman, NJ). A vasovagal response was used by applying digital pressure on the closed lids and eyes for 10 s as described in green iguanas,[7] to prevent motion artifact in less cooperative animals. Radiographs were reviewed with a X-ray/DICOM images viewer (eFilm 2.1, Merge Healthcare, Irvine, CA). Radiographic dorsoventral views were taken at each time point. Based on the pilot study, right lateral views using horizontal beam were taken only every 12 h, as lateral views did not provide enough detail for radiographic interpretation for this species. Lizards were monitored for signs of regurgitation, diarrhea, and other signs of discomfort including abnormal posture, increased agitation, or tenesmus, during eight days following barium administration. A large water dish in which the lizard could drink and soak was reintroduced 72 h after barium administration. Food, as previously described, was offered daily starting 96 h after barium administration. The radiographic study was discontinued four days after barium administration.

The relationship between the lizard's weight and the colon filling time was measured by linear regression and computed Spearman's rank correlation coefficient; the correlation between the lizard gender and the colon filling time was analyzed by a Wilcoxon–Mann–Whitney rank sum test using a the "*R*" statistics software. The statistical significance was set as $P < 0.05$.[15]

Results

The radiographs obtained were of excellent quality, demonstrating each compartment of the gastrointestinal tract with complete filling and good distension. The bearded dragon gastrointestinal tract is composed of an esophagus, a stomach, a duodenal bulb, a short small

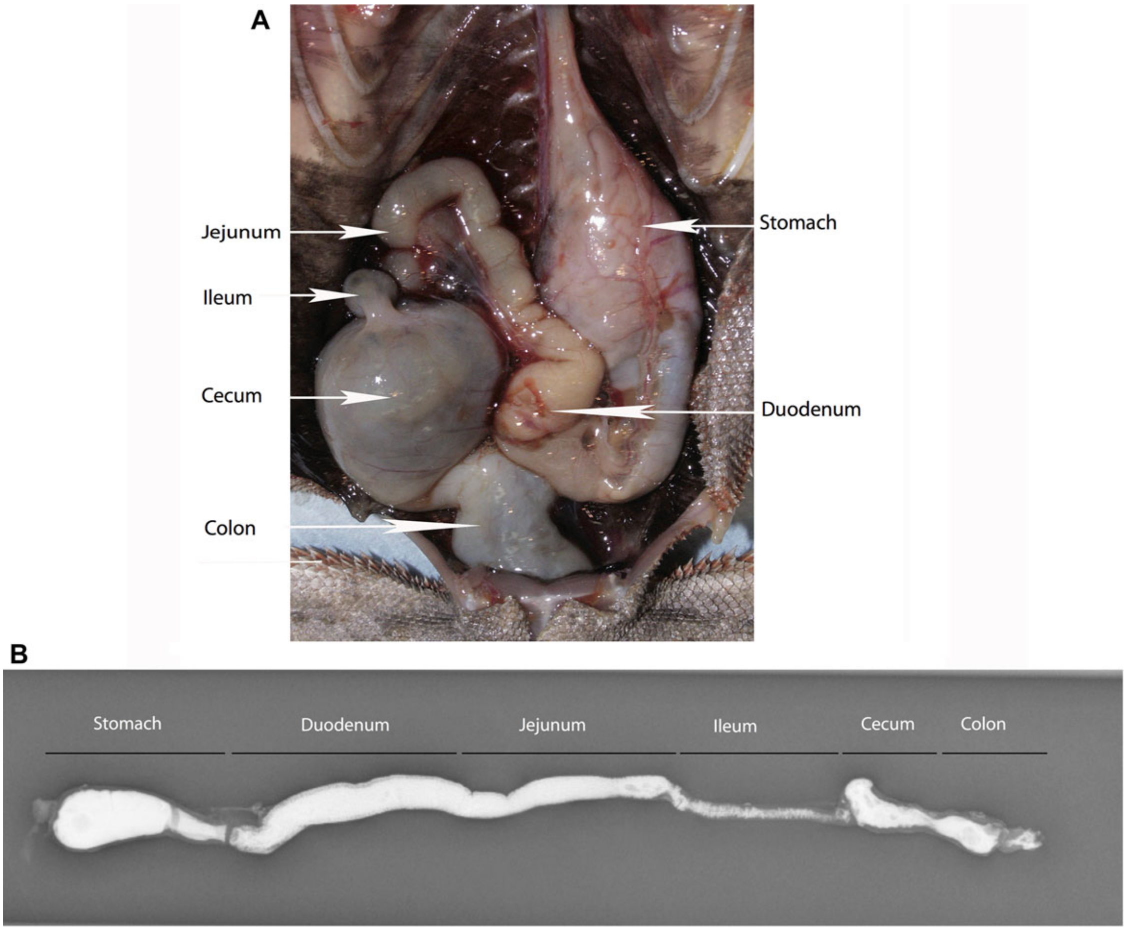

FIG. 1. Anatomy of the digestive tract of a bearded dragon illustrated by a digital image of the ventral view in situ after removal of all non digestive organs (1A), and radiograph of the tract dissected from the body and filled with barium (1B).

intestine, a cecum, and a colon (Fig. 1A and B). Most of the gastrointestinal tract organs were confined to the mid-coelomic region caudal to the heart and liver.

The esophagus traveled dorsally along midline, joining the stomach to the left of midline. Grossly, the esophageal mucosa had longitudinal folds, which were visible as radiopaque lines on the radiographs (Fig. 2). The stomach of all bearded dragons was located on the left side of the body, elongated longitudinally in a J-shape, as previously described,[16] with the small curvature oriented toward midline (Fig. 3A and B). The cardia was observed as an area of smaller diameter than the esophagus, craniomedial to the gastric fundus (Fig. 3C). Rugal folds of the stomach mucosa appeared as radiographic filling defects in the gastric lumen. Radiographically, the pyloric antrum was visible as a distinct narrowing of the stomach body, just proximal to the pylorus. The pylorus was located to the left of midline, caudomedial to the stomach body (Figs. 3A and B).

The proximal duodenum formed a segmental dilatation, termed the duodenal bulb in the green iguana (Figs. 3A and B).[7] The duodenal bulb emerging from the pylorus appeared as an enlargement, with its lumen measuring approximately the same diameter as the pyloric antrum and narrowing at the entry to the proximal duodenum. After the duodenal bulb, the duodenum curved toward the left side of the coelomic cavity, then cranially. After this cranial curvature, the first intestinal loop following the duodenum (termed the jejunum in this study) began medially to the stomach and progressed cranially toward the right, before a dorsal turn cranio-dorsally to the cecum on the right of midline (Fig. 1A and B). The following portion of the small intestine had a small diameter and remained dorsal to the duodenum and cecum. Following the jejunum, the ileum was the last transverse intestinal segment before reaching the cecum (Fig. 4A). The ileum began medially to the stomach and progressed toward the right side of the coelomic cavity, before connecting cranially to the cecum through a small diameter ileo-cecal junction (Figs. 1B, and 4A), which contained a sphincter.

The cecum was very distensible, with a diameter of up to three times the diameter of the colon, mobile, and variable in shape (Fig. 4B, C, and D). The cecum was located

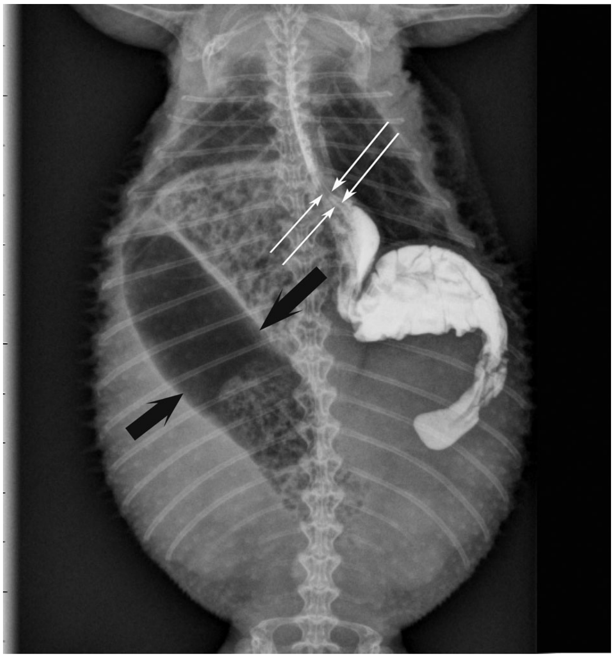

FIG. 2. Radiographic dorso-ventral view of a bearded dragon 15 min following gavage of 15 ml/kg 35% w/v barium suspension into the thoracic esophagus. Contrast in the esophagus provides visualization of esophageal folds (white arrows). The colon is gas-filled on the right of the coelomic cavity (black arrows).

cranio-medially to the colon. The appendix of the cecum was grossly visible, both on the serosal and mucosal surfaces of the cecum, in the medio-cranial quadrant of the cecum and measured approximately 5 mm in length (Fig. 4A). The cecum connected to the colon by a small diameter muscular junction, approximately 5 mm long, located to the right of midline (Fig. 4A and B). Grossly, the mucosa of this ceco-colic junction had longitudinal folds. The colon was a simple tubular structure oriented cranio-caudally, originating from the right side of the coelomic cavity and connecting with the cloaca on midline.

Throughout the study the bearded dragons were active and appeared clinically healthy with exception of one bearded dragon. Retching started two days postbarium administration in this lizard and continued throughout the study. However, no actual vomitus of barium was observed in this animal. Physical examination and biochemistry results remained normal. Restraint and barium administration techniques were well tolerated by every lizard.

In four of the seven bearded dragons, barium was observed in the thoracic esophagus at 15 min following contrast administration. In two of these lizards, barium was also observed in the oral cavity. This was attributed to possible reflux of the contrast suspension, or alternatively to tracking of the contrast material as the tube was withdrawn from the caudal thoracic esophagus. No barium was expelled out of the mouth of the lizards and no barium aspiration was identified radiographically.

The location of the barium at the different time intervals is presented in Table 1 and Figs. 5 and 6. Lateral views did not provide additional information because the barium was mostly confined to the region ventral to the lungs and caudal to the heart, where all the digestive structures were superimposed in the midcoelom, except the esophagus and the colon (Figs. 3C, 7A and B). In most lizards, no radiographic changes were observed between 36 and 96 h after barium administration (Fig. 6). There was no difference in colon filling time between males and females ($P = 0.56$). There was no relationship between body weight and filling time ($r = 0.22$, $P = 0.64$).

On the fourth day following barium administration, all bearded dragons had a normal appetite, passed feces of normal appearance, and displayed expected activity level for the species, including predation, exploration of their environment, and interaction with care-takers. Barium defecation was observed 2–5 days after barium ingestion. However, it was sometimes difficult to distinguish urates from barium, especially when the animals defecated in water.

Discussion

Gastrointestinal studies with contrast agents enable detection of foreign bodies, partially to completely obstructing the digestive tract, intraluminal masses originating from the digestive tract, delayed gastric emptying, and evaluation of the digestive transit time, which can vary with core body temperature, food composition, metabolic factors, such as dehydration or hypocalcemia,[3] metabolic diseases, and digestive infectious agents.[14,17] We described the normal anatomy and imaging characteristics of the gastrointestinal tract of bearded dragons, and established normal transit times in seven healthy adult bearded dragons kept in the preferred optimal temperature range for the species.

Barium sulfate, a noniodinated contrast medium,[18] was chosen in this study because of its excellent quality of contrast, its availability to clinicians and because of its inexpensive cost. Alternative contrast mediums previously studied in reptiles include iodinated water-soluble agents, such as the ionic high-osmolarity contrast agent[18] aminotrizoate sodium and amidotrizoate megumine (Gastrografin®)[10,13] and the nonionic low-osmolarity contrast agent[18] iopamidol (Isovue®).[12] Gastrografin® has a more rapid transit time than barium in red-eared sliders, reaching the large intestine 10 h faster than barium sulfate.[13,17] Although water soluble contrast agents may be chosen in cases where intestinal perforation is suspected[12,16,18] potential adverse effects of hyperosmolar agents include dehydration[12,13,17] and pulmonary edema if aspirated.[18–21] Gastrografin® administered to red-eared sliders had

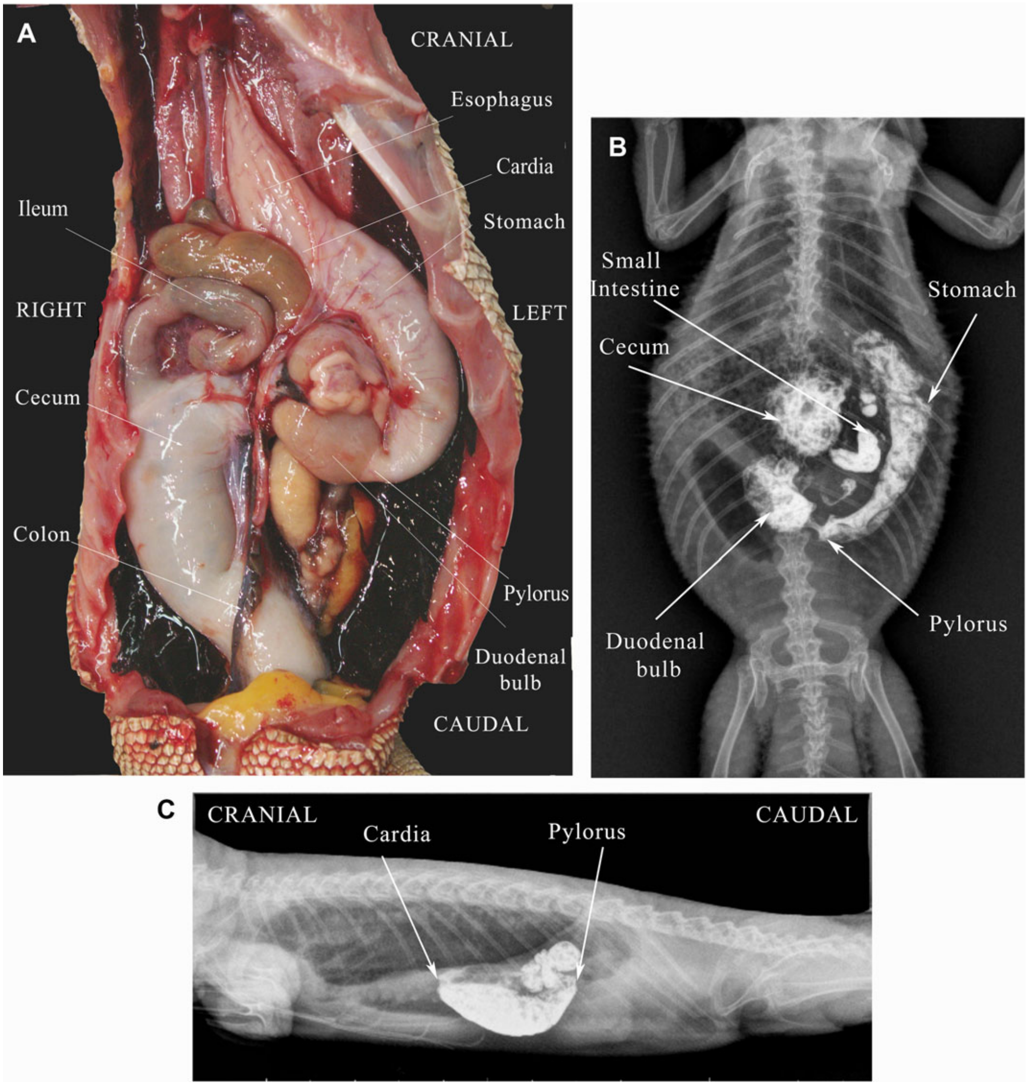

FIG. 3. Anatomy of the digestive tract of a bearded dragon illustrated by a photograph of the ventral view in situ after removal of the liver only (3A) for comparison to the radiologic views; dorso-ventral view (3C) of the same animal at 12 h postbarium administration (3B) and right lateral view at 1 h following gavage of 15 ml/kg of a 35% w/v barium suspension into the thoracic esophagus (3C).

decreased opacity when the contrast reached the colon.[13] Since digestive obstructions in bearded dragons can occur in the distal digestive tract, secondary to renomegaly, barium was chosen in this study, to obtain high contrast opacity in the caudal part of the digestive tract.[7,13] Another alternative in cases of cloacal obstruction would be to perform cloacography, as described in loggerhead sea turtles.[12] Based on the results of this study, cloacography is recommended to investigate a distal obstruction in bearded dragons due to the delay of approximately 29 h before barium enters the colon. In some cases, barium was defecated within 12 h after reaching the colon, requiring frequent radiographic imaging to assess the lumen of the colon. Conversely, barium has been reported to cause digestive obstruction in chelonians, which is not the case of water-soluble hyperosmolar agents.[4,10,13] Barium sulfate can become desiccated in the digestive tract and result in digestive obstruction, especially if a large volume of contrast medium is used and remains in the digestive tract for an extended period of time, due to dehydration, or preexisting ileus.[22] However, digestive obstruction secondary to barium administration has not been reported in bearded dragons or in other lizards,[7] and was not observed in these animals.

In a previous study performed in red-eared sliders, regurgitation was observed in 43% of the animals following rapid administration into the stomach of 8 ml of 30% w/v barium per kg.[13] In these turtles, regurgitation into the oral cavity was grossly visible during administration of the barium whereas in our study reflux was only visible

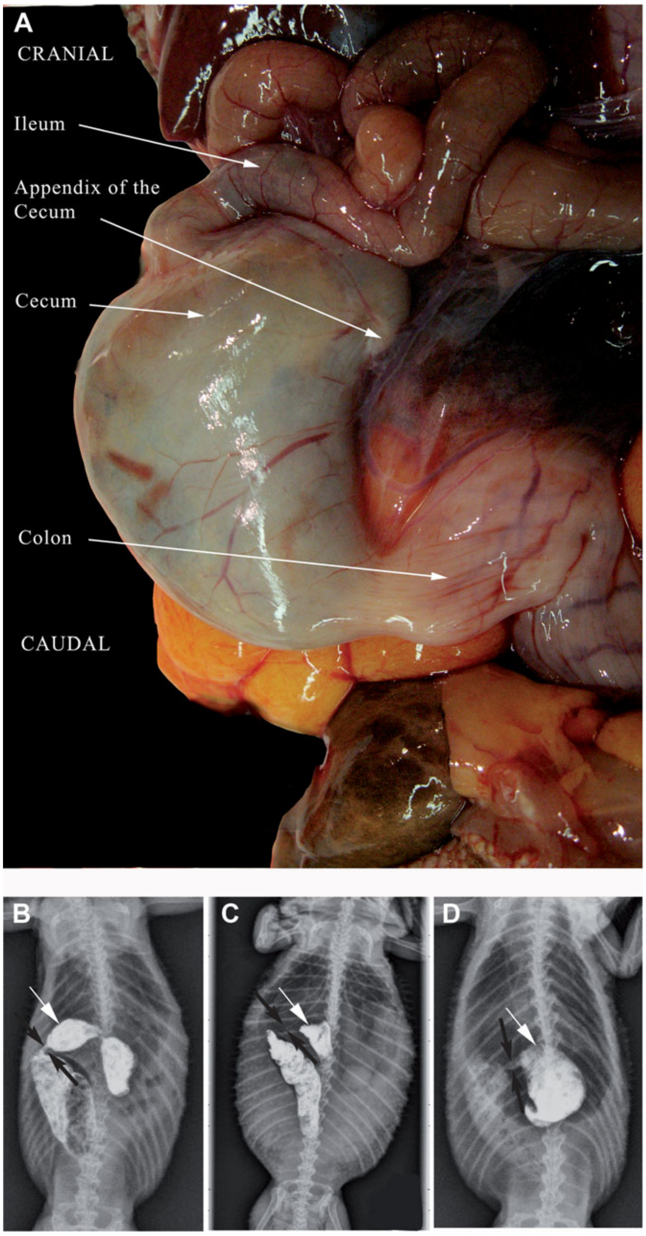

FIG. 4. Comparison between the ventral anatomic view (4A) and the digital image of the radiologic dorso-ventral views (4B, 4C, 4D) of the bearded dragon. On the anatomic image (4A), the cecum has been pulled toward the right and its ventral surface is exposed; the cecum is full and the ileum and the colon are empty. Note the varied radiographic appearance of the ceco-colic junction (black arrows 4B, 4C, 4D) of three bearded dragons 12 h following gavage of 15 ml/kg of a 35% w/v barium suspension into the caudal esophagus. In 4B the ceco-colic junction is filled with barium, in 4C the ceco-colic junction is not visible, and in 4D the ceco-colic junction is visible between the cecum filled with barium and the colon. Note the varied radiologic appearance of the distensible cecum (white arrows 4B, 4C, 4D), which should not be confused with the stomach (not visible on these radiographic views) when the cecum is displaced toward the left (4D).

radiographically. The same dose was appropriate when the contrast medium was administered over a period of 20 s.[13] In ball pythons, a dose of 25 ml/kg was associated with regurgitation in four of 18 snakes.[8] In green iguanas, a dose of 25 ml/kg of 25% w/v barium resulted in regurgitation in three out of five animals and a smaller dose was recommended by the authors.[7] In the current study, a dose of 15 ml/kg was elected and provided appropriate distension of the gastrointestinal tract, despite more than half of the animals showing reflux into the cranial esophagus. Some of the contrast appearing in the esophagus could also be associated with tracking of the contrast material as the tube was withdrawn from the caudal thoracic esophagus. In red-eared sliders, a concentration of 30% w/v barium sulfate was recommended,[13] in ball pythons a concentration of 35% w/v was preferred compared to either 25% or 45% w/v,[8] whereas in green iguanas, a dilution of 25% w/v was considered more appropriate than nondiluted 105% w/v barium sulfate.[7] Similarly, in the bearded dragons of the study presented here, good quality images of the digestive tract were obtained with a concentration of 35% w/v, and excellent distension of each portion of the gastrointestinal tract was obtained.

The storage compartment located between the small intestine and the colon was called the cecum in this study. To the authors' knowledge, digestive anatomy of healthy bearded dragons has not been described in detail previously. A recent study described bearded dragons' coelomic organs, referring to the nomenclature established in green iguanas.[16] However, this study was performed in four bearded dragons euthanized due to advanced clinical conditions and not in healthy animals.[16] The current study combined anatomic description and radiographic gastrointestinal positive contrast information, to identify and confirm gastrointestinal tact segments based on their function. Some discrepancies were observed between our results and those previously published.[16] An "ascending stomach" was described medial to the gastric fundus, with the pylorus located distal to this segment; however in our study, when combining radiographic and anatomic views, the pylorus was localized caudal to the gastric fundus, as noted on Fig. 5. Therefore we would call the previously termed "ascending stomach" a duodenal bulb, since it is aboral to the pyloric sphincter.

In addition, an ascending and a transverse colon were described in the same study,[16] which were not observed in the bearded dragons of the study presented here. No cecum was described in bearded dragons in this comparative study about bearded dragons, green iguanas, and black

TABLE 1. Barium Contrast Agent Transit Time (h) in the Digestive Tract of Bearded Dragons ($n = 7$) with the Weight (g) and Gender of each Bearded Dragon Recorded (One Individual per Column and Median in the First Column): Time (h) When Barium First Entered (Arrival, h) and Had Completely Emptied (Exit, h, If Applicable) each Segment of the Gastrointestinal Tract

Animal number:	Median	1	2	3	4	5	6	7
Animal weight (in g)		150	294	256	163	282	262	297
Animal gender	N/A	M	M	M	F	F	F	M
Oral cavity (arrival, h)	N/A		0.25		0			
(exit, h)	N/A		0.5		0.25			
Esophagus (arrival, h)	N/A	0.25	0	0	0	0	0	0
(exit, h)	0.68	0.5	0.5	1	0.25	0.25	2	0.25
Stomach (arrival, h)	0	0	0	0	0	0	0	0
(exit, h)	10	4	24	6	6	12	6	12
Pylorus (arrival, h)	0.14	0	0	0.25	0.5	0.25	0	0
(exit, h)	9	6	24	6	6	6	4	8
Duodenum (arrival, h)	0.4	0.25	0.25	0.25	0.5	0.5	0.25	1
(exit, h)	13	6	36	24	6	6	4	8
Jejunum and ileum (arrival, h)	1.4	0.5	1	1	2	2	2	1
(exit, h)	29	24	36	48	24	24	24	24
Cecum (arrival, h)	10	12	8	12	8	8	8	12
(exit, h)	N/A				96	48		
Colon (arrival, h)	31	24	24	24	36	24	12	72

and white tegu (*Tupinambis merianae*) coelomic organs.[16] Furthermore, the appendix was not described,[16] contrary to what is reported in the present study (see Fig. 4A). The gastro-intestinal anatomy of closely related species has been described, including the common agama (*Agama agama*),[23] and *Uromastyx* spp.[24] In these species, a cecum has been described with a homologous position as what is observed in bearded dragons.[23] The tip of the cecum has been called "appendix"[24] and contains individual lymphatic follicles.[25] Natural diet is not the only predictor of the occurrence and size of a cecum in reptiles.[26,27] In Iguanidae lizards, a homologous compartment of the digestive tract has been called alternatively "large colon,"[7,28] or "cecum."[23] In lizards, the cecum histologic morphology is thought to be identical to the histologic morphology of the colon,[25] therefore the designation of the storage compartment is a convention. In the eleven bearded dragons in this study, the distension of the compartment cranial to the colon was highly variable and its diameter was sometimes the same as the diameter of the colon. Therefore it was designated as the cecum in this study. Whether fermentation occurs in the bearded dragon cecum is beyond the scope of this study, however contrast was stored in the cecum for up to 96 h (Table 1). It is relevant to know that the cecum can be highly distensible and mobile in the coelomic cavity, and the cecum should not be mistaken for a dilation of the digestive tract proximal to an obstruction. Most of the Iguanidae lizards display one to eleven transversal valves in their proximal colon.[29] Some lizards of the family Aguamidae, such as *Agama stellio*, *Gonyocephalus* sp. and *Physignathus leseuri* do not have any colic valves,[23] which was also the case in bearded dragons. Conversely, the lizards of the genus *Uromastyx* sp., which belong to the Agamidae family, display colic partition.[23]

In reptiles, barium gastrointestinal transit is influenced by environmental temperature,[7] exercise, health status, diet items,[17,29] and the stage of digestion.[8] In this study, lizards were fasted for 106 h, beginning 10 h before barium administration. This experimental protocol was intended to reduce individual variability due to variable food ingestion, and to reproduce the common clinical situation for a bearded dragon presented with anorexia. Recommended feeding frequency for adult bearded dragons varies between once a day to twice a week,[1] therefore a four and a half-day fasting period was considered compatible and within the range of the species normal captive husbandry recommendations. In previous studies in green iguanas, food, and water were available at all times, which made the interpretation of the study results challenging for application to ill lizards.[7]

Bearded dragon gastric emptying time was 10 h in this study, which is similar to the green iguana,[7] however the individual variability was higher in bearded dragons, respectively, 4–24 h vs. 6–12 h in iguanas.[7] In comparison leopard geckos have been shown to keep mealworms for up to 52 h in their stomach.[30] Compared to the green iguana that displays a U-shaped stomach centrally positioned,[7,28] the stomach of bearded dragons was J-shaped and was lateralized on the left coelomic cavity as previously described.[16] In some cases when the stomach did not contain any barium, the cecum could easily be confused as the stomach (Fig. 4D). However, the stomach was always more lateral than the cecum on the left side of the coelomic cavity. Given the small diameter of this sphincter and the normal distension of the cecum, this could be misinterpreted as a partial obstruction of the digestive tract when reviewing radiographs, but it is anatomically normal in bearded dragons. In addition, the ceco-colic junction was free of barium in

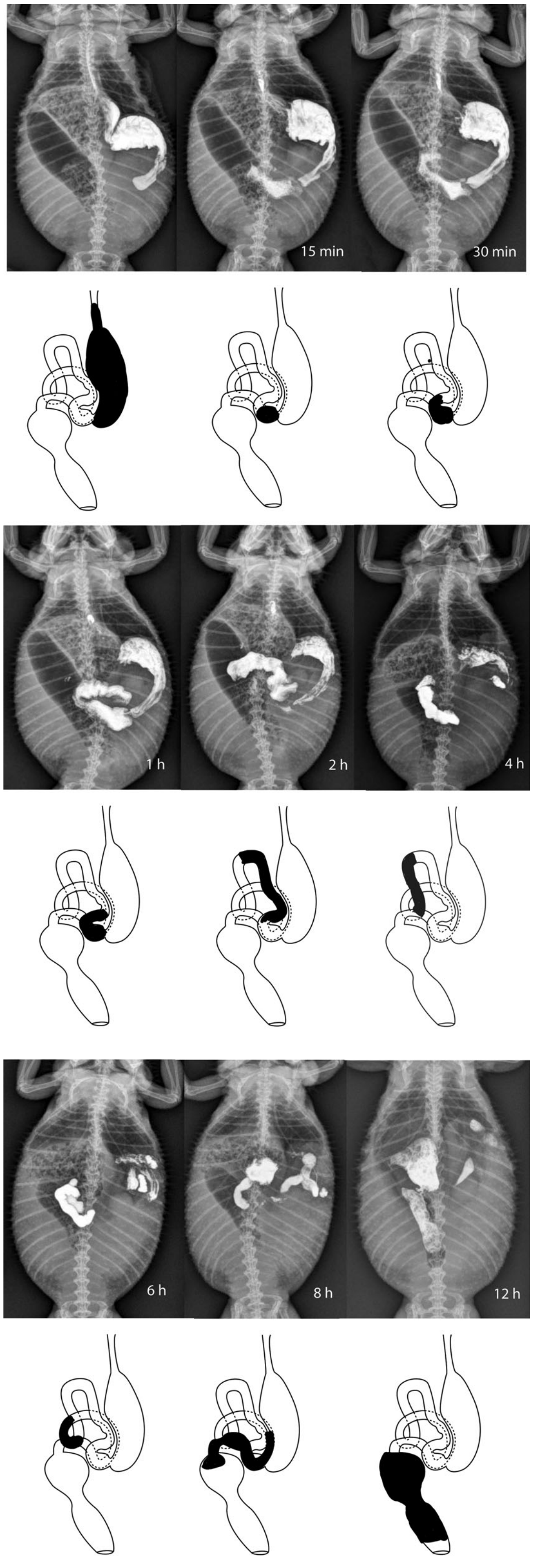

FIG. 5. Contrast-enhanced dorso-ventral radiographic images and associated schematic drawings of bearded dragons immediately following gavage of 15 ml/kg of a 35% w/v barium suspension into the caudal esophagus to 12 h postadministration.

most of the views and should not be mistaken for a foreign body.

In bearded dragons, time for barium to reach the duodenal bulb was longer, that is 15 min, compared to immediately after contrast administration in green iguanas.[7] Jejunum transit time was quicker in the bearded dragons from this study than in green iguanas, respectively, 1.4 h vs. 4 h. Small intestine emptying time was almost twice as long in bearded dragons (median 29 h) compared to green iguanas (median 16 h).[7] This could be due to the different gastrointestinal anatomy or differences in natural dietary requirements between the green iguana and the bearded dragon, with the cecum having a storage function in bearded dragons, or it could be associated with fasting the bearded dragons in this study whereas the green iguanas had access to food.[7] However, this should not have affected the gastric emptying time because gastric tone is generally unchanged during the fast.[31] Overall, little information was gained from lateral views in healthy bearded dragons, however, these additional views may be helpful in diseased lizards to visualize and characterize a potential lesion. Bearded dragon and green iguana gastrointestinal transit times appear to be different, which would be expected since they belonging to distinct lizard families, that is Iguanidae and Agamidae, which differ by many anatomic features.[32] Moreover green iguanas and bearded dragons have different husbandry and dietary requirements, adult bearded dragons being omnivorous[1] and green iguanas being herbivorous from birth.[31,33] Gastrointestinal transit time in carnivorous lizards species has been reported to be shorter than in herbivorous species.[17] Juvenile bearded dragon are more omnivorous than adults,[1] therefore results obtained from our study may not apply to younger animals eating more insects. In addition, bearded dragons originate from arid to semi-arid environments in Australia,[1] whereas green iguanas come from more humid environments in America.[33] Green iguanas tend to favor food items with high water content, such as flowers, during dry season, whereas vegetables higher in protein are consumed during rainy season.[29] Various food items have been shown to be associated with various transit times.[29] Whether longer transit time in bearded dragon is associated with increased water reabsorption would require further investigation. Similar study design with fasted animals would be necessary to accurately compare gastrointestinal transit of various lizard species and ages.

Interindividual variability was observed among bearded dragons (Table 1), although care was taken to standardize the ambient temperature. Interindividual variability was not associated with the gender of the lizard and the transit time did not correlate with the body weight of the animals. This may have been due to physiologic causes or to various gastrointestinal digestive phases when the study was started, although the lizards were fasted for ten hours

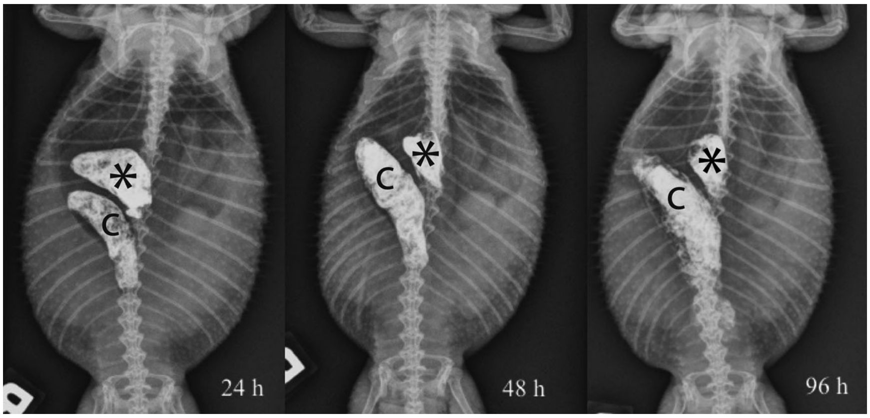

FIG. 6. Contrast-enhanced dorso-ventral radiographic images from a bearded dragon 24–96 h following gavage of 15 ml/kg of a 35% w/v barium suspension into the caudal esophagus (* = cecum, C = colon). Three views were selected during the time period because of the lack of progression of the contrast medium.

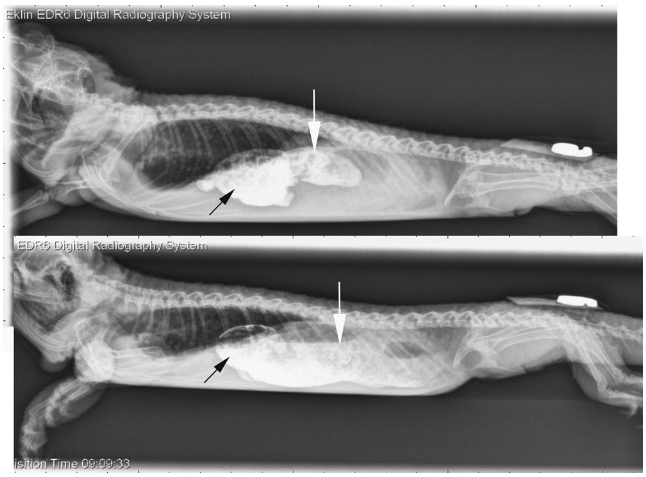

FIG. 7. Contrast-enhanced right lateral radiographic images of a bearded dragon: 12 h (7A) and 96 h (7B) after gavage of 15 ml/kg of a 35% w/v barium suspension: the cecum (black arrow) and colon (white arrow) are visible on lateral views.

prior to the study. Interestingly, various distribution patterns have also been observed in ball python fasted for seven days prior to a digestive contrast study.[8] In leopard geckos, total transit time also varied between 49 and 219 hours in lizards fed the same mealworm diet.[30] Vasovagal response has been suspected to influence digestive transit due to its effects on autonomic nervous system, but this assumption has not been demonstrated in a controlled study.[7] A restraint method using cotton balls held in place with a bandage around the head to apply continuous pressure on the eyes was not used in the current study to minimize possible influence on the gastrointestinal tract. In this study, pressure on the lizards' eyeballs was performed for approximately five to ten seconds, if necessary to position for a radiograph. Therefore we do not expect this very rapid vaso-vagal response to have significantly influenced the results. Moreover, in a clinical situation where the patient is not sedated or anesthetized, this method could be used and the radiographs compared to the results of the present study.

Conclusion

Barium administration at a dose of 15 ml/kg by gavage in the thoracic esophagus in seven fasted bearded dragons was appropriate to study gastro-intestinal transit time for 96 h postcontrast administration and to evaluate the bearded dragon gastrointestinal anatomy in detail. Inter-individual variability was observed, therefore a possible limitation of this study is the low number of animals included, however, reference intervals for gastric transit were similar to a study reported in adult green iguanas. Intestine emptying time was longer in this bearded dragon study than in green iguanas, which is likely due to different anatomy, dietary and husbandry requirements between the two species although various study designs may have accounted for part of the differences observed. No significant adverse clinical signs were observed following barium the gastrointestinal contrast study. Therefore this technique appears both safe and informative to evaluate the gastrointestinal tract of bearded dragons.

ACKNOWLEDGEMENTS

The authors thank Dr. Kate Gustavsen, for her help regarding the statistical analysis, the technicians of the Small Animal Radiology Service for their technical assistance, especially Michele Santoro, Linda Savely, and Jennifer Lazzari, and the technicians of the Companion Avian and Exotic Pet Medicine Service of the University of California-Davis, especially Kristina Palmer-Holtry, Stacey Zindel, Sheri Pendergraft, Nikki Reid for their logistical assistance and Delphine Grosset, Visual Communication Conception Creator, for her assistance with Fig. 5 drawing.

REFERENCES

1. Cannon M. Husbandry and veterinary aspects of the bearded dragon (*Pogona* spp.) in Australia. Sem Avian Exotic Pet Med 2003;12:205–214.

2. Knabe J. Impact assessment of importing a live inland bearded dragon (*Pogona vitticeps*) into Australia as a household pet. Dept Environ Heritage 2006:1–27.

3. Wright K. Two common disorders of captive bearded dragons (*Pogona vitticeps*): nutritional secondary hyperparathyroidism and constipation. J Exotic Pet Med 2008;17:267–272.

4. Martinez-Jimenez D, Hernandez-Divers SJ. Emergency care of reptiles. Vet Clinics North Am: Exotic An Pract 2007;10:557–585.

5. Ritter JM, Garner MM, Chilton JA, et al. Gastric neuroendocrine carcinomas in bearded dragons (*Pogona vitticeps*). Vet Pathol 2009;46:1109–1116.

6. Perpinan D, Addante K, Driskell E. What is your diagnosis? Gastrointestinal disturbances in a bearded dragon (*Pogona vitticeps*). J Herp Med Surg 2010;20:54–57.

7. Smith D, Dobson H, Spence E. Gastrointestinal studies in the green iguana: technique and reference values. Vet Radiol Ultrasound 2001;42:515–520.

8. Banzato T, Russo E, Finotti L, et al. Development of a technique for contrast radiographic examination of the gastrointestinal tract in ball pythons (*Python regius*). Am J Vet Res 2012;73:996–1001.

9. Taylor SK, Citino SB, Zdziarski JM, et al. Radiographic anatomy and barium sulfate transit time of the gastrointestinal tract of the leopard tortoise (*Testudo pardalis*). J Zoo Wild Med 1996;27:180–186.

10. Meyer J. Gastrografin as a gastrointestinal contrast agent in the Greek tortoise (*Testudo hermanni*). J Zoo Wildl Med 1998;29:183–189.

11. Reidarson TH, Jantsch CA, Gendron SM. Medical treatment for multiple foreign objects in a hawksbill turtle (*Eretmochelys imbricata*). J Zoo Wild Med 1994;25:158–160.

12. Di Bello A, Valastro C, Staffieri F, at al. Contrast radiography of the gastrointestinal tract in sea turtles. Vet Radiol Ultrasound 2006;47:351–354.

13. Long CT, Page RB, Howard AM, et al. Comparison of gastrografin to barium sulfate as a gastrointestinal contrast agent in red-eared slider turtles (*Trachemys scripta elegans*). Vet Radiol Ultrasound 2010;51:42–47.

14. Mitchell MA, Diaz-Figueroa O. Clinical reptile gastroenterology. Vet Clin North Am: Exotic An Pract 2005;8:277–298.

15. R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. 2012. ISBN 3–900051–07–0, http://www.R-project.org/.

16. Banzato T, Selleri P, Veladiano IA, Zotti A. Comparative evaluation of the cadaveric and computed tomographic features of the coelomic cavity in the green iguana (*iguana iguana*), black and white tegu (*tupinambis merianae*) and bearded dragon (*Pogona vitticeps*). Anat histol embryol 2013;42:1–8.

17. Shumaker J, Toal RL. Advanced radiography and ultrasonography in reptiles. Sem Avian Exotic Pet Med 2001;10:162–168.

18. American College of Radiology. Committee on drugs and contrast media. iodinated gastrointestinal contrast media in adults: indications and guidelines. In: Radiology ACo (ed): ACR manual on contrast media, 8th ed. ACR, 2012;55–57.

19. Mishkin D, Carpenter S, Croffie J, et al. ASGE technology status evaluation report: radiographic contrast media used in ERCP. Gastrointestinal Endoscopy 2005;62:480–484.

20. Ginai AZ. Experimental evaluation of various available contrast agents for use in the gastrointestinal tract in case of suspected leakage. Effects on pleura. The British J Radiol 1986;59:887–894.

21. Ginai AZ, ten Kate FJW, ten Berg RG, et al. Experimental evaluation of various available contrast agents for use in the upper gastrointestinal tract in case of suspected leakage. Effects on lungs. The British J Radiol 1984;57:895–901.

22. Silverman S . Diagnostic imaging. In: Mader D (ed): Reptile medicine and surgery, 2nd ed. St. Louis, MO: Elsevier-Saunders, 2006;471–489.

23. Henke J. Vergleichend-morphologische Untersuchungen am Magen-Darm-Trakt der Agamidae und Iguanidae. Zoolog Jahrbücher Abteilung Anat Ontog Tiere 1975;94:505–569.

24. Zaher M, El-Ghareeb AW, Hamdi H., et al. Anatomical, histological and histochemical adaptations of the reptilian alimentary canal to their food habits: I. Uromastyx aegyptiaca. Life Science 2012;9:85–104.

25. Gans C, Morphology B. In: Gans CPT (ed): Biology of the reptilia. New York, NY: Academic Press, 1977;1–720.

26. Lönnenberg E. On some points of relation between the morphological structure of the intestine and the diets of the reptiles. Bih Svensk Vet Ak Handl 1902;28:1–51.

27. Skoczylas R. Physiology of the Digestive Tract. In: Gans C (ed): Biology of the reptilia. New York: Academic Press, 1978;589–667.

28. Iverson JB. Colic modifications in iguanine lizards. J Morphol 1980;163:79–93.

29. van Marken Lichtenbelt WD. Optimal foraging of a herbivorous lizard, the green iguana in a seasonal environment. Oecologia 1993;95:246–256.

30. Koelle P, Reese S. Digestion in leopard gecko (*Eublepharis macularius)*. Proceedings of the Annual conference of the Assoc Reptilian Amphibian Vet. Oakland, CA, 2012;4:

31. Diaz-Figueroa O, Mitchell MA. Gastrointestinal anatomy and physiology. In: Mader D (ed): Reptile medicine and surgery, 2nd ed. St. Louis, MO: Saunders Elsevier, 2006;145–162.

32. Throckmorton GS. Oral food processing in two herbivorous lizards, *Iguana iguana* (Iguanidae) and *Uromastix aegyptius* (Agamidae). J Morphol 1976;148:363–390.

33. Barten S. Chapter 6: lizards. In: Mader D (ed): Reptile medicine and surgery, 2nd ed. St. Louis, MO: Saunders Elsevier, 2006;59–77.