https://doi.org/10.17221/50/2020-VETMED

Marine debris ingestion and the use of diagnostic imaging in sea turtles: A review

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Citation: Oliveira REM, Attademo FLN, Moura CEB, Araujo Junior HN, Costa HS, Reboucas CEV, Silva FJL, Oliveira MF (2020): Marine debris ingestion and the use of diagnostic imaging in sea turtles: A review. Vet Med-Czech 65, 511–527.

Abstract: Worldwide, sea turtles are affected by anthropic waste. Animals, unable to differentiate anthropic waste from food, ingest this waste from their surroundings. After ingestion, the waste may cause a digestive tract blockage, thereby compromising the feeding and digestion capacity of the turtles, causing malnutrition, which may lead to death. Radiological imaging can be performed in turtles under rehabilitation to identify alterations of the digestive tract, such as intussusceptions, impactions, obstructions, torsions, neoplasms, and foreign bodies. These alterations are a result of either the ingestion of anthropogenic residues or natural causes. Moreover, diagnostic imaging exams play an important role in interventional medicine as they can indicate the location and type of ingested waste, thereby facilitating decision-making for the treatment of the afflicted animals. The aim of this study was to analyse the published scientific literature surrounding the effects of the ingestion of anthropogenic residue by sea turtles and the main imaging modalities used for their diagnosis. This was undertaken to provide clinicians with a greater amount of information regarding the digestive tract diseases of these animals and consequently, provide better outcomes of the rehabilitation processes. Furthermore, the outcomes of this study provide key information regarding the conservation of these species, among others.

Keywords: Cheloniidae; morphology; plastic; Testudines

Financed by Coordination for the Improvement of Higher Education Personnel – Brazil (CAPES, Financial Code 001).

Veterinarni Medicina, 65, 2020 (12): 511–527

https://doi.org/10.17221/50/2020-VETMED

Contents

1. Introduction

The impact of anthropic waste intake is one of the greatest problems for marine fauna conservation worldwide (Derraik 2002; Gregory 2009; Hoarau et al. 2014; Gall and Thompson 2015; Poli et al. 2015; Clukey et al. 2017; Pham et al. 2017; Duncan et al. 2019; Rizzi et al. 2019), affecting mammals (Baulch and Perry 2014; Attademo et al. 2015; Poeta et al. 2017; Fossi et al. 2018), birds (Cadee 2002; Provencher et al. 2014; Provencher et al. 2015; Perez et al. 2019), turtles (Lazar and Gracan 2011; Gall and Thompson 2015), fishes, and molluscs (Rochman et al. 2015). This waste, regardless of its origin, remains in the environment and the animals ingest it by confusing it with food (Rizzi et al. 2019). This can cause digestive tract blockages (Laist 1997), which compromises the animal's feeding and digestion capacity, resulting in malnutrition, disease, reduced growth and reproduction rates, and even death (McCauley and Bjorndal 2001).

Sea turtles belong to the order Testudines and form a monophyletic group of the suborder Cryptodira (Bowen and Karl 1997; Meylan and Meylan 1999). The seven known species of sea turtles are distributed in two families: *Dermochelys coriacea*, or the leatherback sea turtle, belongs to the Dermochelyidae family, while the other six species: *Chelonia mydas* (green sea turtle), *Caretta caretta* (loggerhead sea turtle), *Eretmochelys imbricata* (hawksbill sea turtle), *Lepidochelys kempii* (Kemp's ridley sea turtle), *Lepidochelys olivacea* (olive ridley sea turtle), and *Natator depressus* (flatback sea turtle) (Meylan and Meylan 1999), belong to the Cheloniidae family.

Sea turtles have a complex life cycle and population structure characterised by migrations from hundreds to thousands of kilometres between feeding and spawning areas (Bowen 1995). They face various threats during these migrations, including pollution, loss of habitat, climate change, interactions with fishing practices, and the ingestion of marine waste of anthropogenic origin (Bugoni et al. 2001; Fujihara et al. 2003; Keller et al. 2004; Thompson et al. 2009; Hamann et al. 2010). The presence of waste in the digestive tract is a primary cause of digestive system organ rupture, which leads to death (Oros et al. 2004; Fichia et al. 2016; Farias et al. 2019).

The ingestion of anthropic waste has been reported in all sea turtle species (Macedo et al. 2011; Awabdi et al. 2013; Poli et al. 2015; Schuyler et al. 2016; Wilcox et al. 2018; Rizzi et al. 2019). This indicates the importance of assessing the effects and impacts of marine waste on the development, survival, health, and reproduction of sea turtles, which has become a worldwide research priority (Hamann et al. 2010; Hoarau et al. 2014; Gall and Thompson 2015; Poli et al. 2015; Nelms et al. 2016; Clukey et al. 2017; Pham et al. 2017; Duncan et al. 2019; Rizzi et al. 2019).

The main clinical findings that have been associated with the digestive tract of sea turtles are constipation, obstructions, ulcerations, perforations, necroses, neoplasms, torsions, paralytic ileum, intussusceptions, parasitic infections, and the presence of foreign bodies (Bugoni et al. 2001; Torrent et al. 2002; De Vico et al. 2003; Croft et al. 2004; Oros et al. 2004; Santoro et al. 2006; Werneck et al. 2008; Wyneken et al. 2013; Oliveira et al. 2020a; Oliveira et al. 2020b). In most cases, these findings result from the ingestion of man-made pollutants, such as plastics, nylon strands, rubber, metals, and fishing hooks (Bugoni et al. 2001; Andrady 2011;

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Wyneken et al. 2013; Clukey et al. 2017; Caracappa et al. 2018; Duncan et al. 2019).

An *ante-mortem* diagnosis of digestive tract diseases is difficult to obtain within a crucial time period. Accurate and detailed knowledge of suitable diagnostic imaging exams for the correct interpretation of alterations to the digestive tract caused by the ingestion of anthropic residue is required (Pressler et al. 2003; Di Bello et al. 2006; Valente et al. 2007a; Valente et al. 2007b; Erlacher-Reid et al. 2013; De Majo et al. 2016; Spadola et al. 2016b). An early diagnosis, associated with surgical correction, of anthropic waste ingestion is fundamental for the successful treatment of animals in rehabilitation centres. This disorder, when correctly identified and treated, can allow a better prognosis for the animal, depending on the object present and its location in the digestive tract. Most digestive tract disorders in animals are associated with anthropic waste and pollutants. As a result, diagnostic imaging exams are necessary for better outcomes in turtles kept in rehabilitation centres. Therefore, we conducted a bibliographic survey of published studies regarding the effects of the ingestion of anthropic waste by these animals as well as the main imaging procedures used for the diagnosis. This was undertaken to enable greater success in the rehabilitation processes, and consequently, promote the dissemination of important knowledge regarding conservation actions for sea turtles.

2. Morphology of the sea turtle digestive system

Imaging exams conducted on sea turtles require prior knowledge of the animal's morphology. Therefore, the macroscopic and topographic morphologies of the digestive tract of sea turtles are addressed in this section.

The digestive tract of sea turtles comprises the tongue, oesophagus, stomach, small intestine (duodenum, jejunum, and ileum), large intestine (caecum, colon, and rectum), and cloaca (Figure 1) (Wyneken 2004; Magalhaes et al. 2010; Magalhaes et al. 2012; Chen et al. 2015; Calais Junior et al. 2016).

2.1 TONGUE

Sea turtle tongues are triangular with a slightly rounded apex when viewed from the back. There

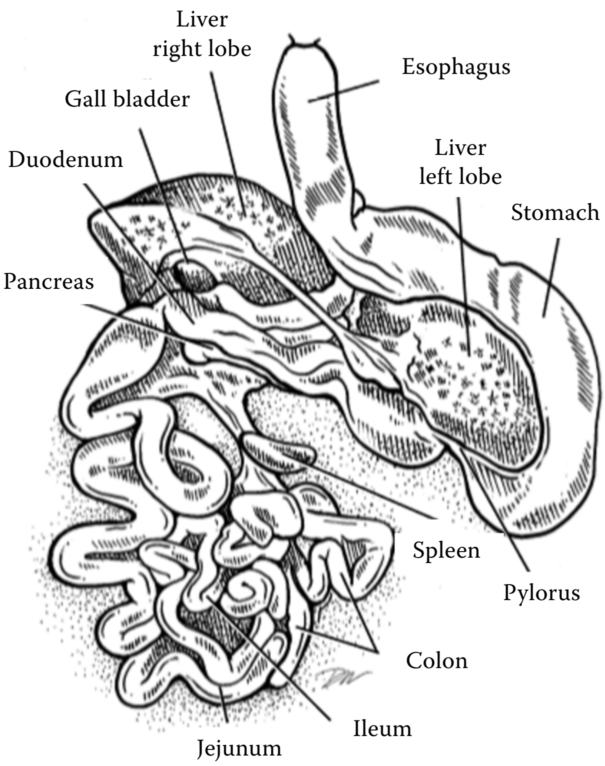

Figure 1. The digestive system of a sea turtle (*Lepidochelys kempii*)
Source: Modified after Wyneken (2004)

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are no papillae present on the dorsal surface; instead, numerous folds are present there as well as at the root of the tongue. This can be viewed with a scanning electron microscope (Iwasaki et al. 1996).

2.2 OESOPHAGUS

The oesophagus of *C. caretta*, *C. mydas*, *E. imbricata*, and *L. olivacea* consists of a muscular-membranous tubular organ, medially located in the cervical region, which diverts laterally to the left in the celomic region (Magalhaes et al. 2010; Magalhaes et al. 2012). The oesophagus of *D. coriacea*, on its turn, is exceptionally long (up to 167.00 cm) and extends for almost half of the turtle's body length, and then turns to the left and enters the stomach (Wyneken 2004; Magalhaes et al. 2012).

The oesophageal mucosa of all seven species of sea turtles is characterised by pointed papillae along its entire length (oesophageal papillae). These papillae are caudally oriented and become progressively larger in the more caudal portion of this organ, with this being limited to its junction with the stomach (Wyneken 2004; Magalhaes et al. 2010; Magalhaes et al. 2012; Calais Junior et al. 2016).

2.3 STOMACH

Sea turtle stomachs are located in the left antimere and form a curve around the liver and pericardium. From the caudal portion of the oesophagus, the cardiac region is formed followed by a large pouch, the fundic region, and finally, the pyloric region, a short muscular region, is formed to the right. This is connected to the left lobe of the liver by a gastrohepatic ligament and to the left lung by a gastropulmonary ligament (Wyneken 2004; Magalhaes et al. 2012).

The stomach mucosa is characterised by longitudinal folds. These folds disappear when the stomach is stretched, giving the impression that the stomach is an organ without folds (Magalhaes et al. 2010; Magalhaes et al. 2012).

2.4 SMALL INTESTINE

The small intestine is divided into three regions; the duodenum, jejunum, and ileum. The duodenum mucosa is marked by the presence of reticular folds with a "honeycomb or beehive-like" arrangement. This textured coating is associated with an increase in the contact surface of the mucosa. The transition from the duodenum to jejunum is characterised by a change in the mucosa, where the folds change from reticular to rectilinear. The jejunum and ileum have juxtaposed rectilinear folds (Wyneken 2004; Magalhaes et al. 2010; Magalhaes et al. 2012).

The transitions between the components of the small intestine (duodenum, jejunum, and ileum) are difficult to identify. Macroscopic differences are often not obvious and are best confirmed by a histological analysis. The transition between the ileum and colon is obvious in adult animals, where the ileum ends in the ileocaecal valve, which is a muscular sphincter (Wyneken 2004; Magalhaes et al. 2012).

2.5 LARGE INTESTINE

The caecum is located at the proximal extremity of the colon and is a slightly larger sac than the rest of the intestine. It is best differentiated in green and leatherback adult sea turtles and is less pronounced in carnivorous and omnivorous species (Wyneken 2004).

The colon is characterised by the alternation of domed regions represented by sacculation and narrowing. The domed regions show smooth mucosa, and the narrowing is characterised by rectilinear folds. The caudal region, referred to as the rectum, is marked by rectilinear folds (Magalhaes et al. 2010; Magalhaes et al. 2012).

2.6 CLOACA

The sea turtle cloaca is characterised by a chamber that collects the faeces, urine, eggs, and semen flow and is connected ventrally to the urinary bladder.

The cloaca opens to the exterior and is divided into three compartments; the coprodeum, urodeum, and proctodeum. The coprodeum receives the faeces from the rectum, while the urodeum contains the urinary papillae and the opening of the bladder. The proctodeum corresponds to the most distal region of the cloaca and contains the genital ducts of the male or female and is associated with copulation (Wyneken 2004).

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3. Ingestion of anthropic waste and its effects

All seven species of sea turtles are globally affected by the impact of anthropic waste, either by getting entangled in or ingesting these materials (Lazar and Gracan 2011; Gall and Thompson 2015; Schuyler et al. 2016; Caracappa et al. 2018; Wilcox et al. 2018; Rizzi et al. 2019). Previous studies have shown that *C. mydas* and *C. caretta* are the most affected species (Lazar and Gracan 2011; Hoarau et al. 2014; Gall and Thompson 2015; Poli et al. 2015; Fukuoka et al. 2016; Schuyler et al. 2016; Pham et al. 2017; Caracappa et al. 2018; Rizzi et al. 2019), followed by *L. olivacea*, *E. imbricata*, *D. coriacea*, *L. kempii*, and *N. depressus* (Gall and Thompson 2015; Schuyler et al. 2016; Wilcox et al. 2018; Rizzi et al. 2019). Different eating habits are observed in sea turtles; their diet ranges from needle grass, algae, sponges, cnidarians, fishes, and crustaceans (Den Hartog 1979; Spotila 2004; Colman et al. 2014). However, man-made solid or contaminating waste affects these turtles through both waste ingestion and a decrease in their food stock as a result of pollution.

Fishing equipment represents one of the main causes of mortality for sea turtles, mainly affecting *C. caretta* (Figure 2) (Silva et al. 2010). Caracappa et al. (2018) reported the presence of fishing hooks in 129 samples of *C. caretta* captured incidentally off the coast of Sicily. These hooks were located in different sections of the digestive tract, but were mostly found in the oesophagus (47.3%) followed by the intestines (24.8%), stomach (14.7%), and mouth (13.2%).

Another major threat, which is also the most worrying threat, is the ingestion of waste (Lazar and Gracan 2011; Gall and Thompson 2015; Caracappa et al. 2018; Rizzi et al. 2019), which, in most cases, causes intestinal obstructions and internal injuries, resulting in deficits in the digestion and nutrient absorption, causing malnutrition and increased

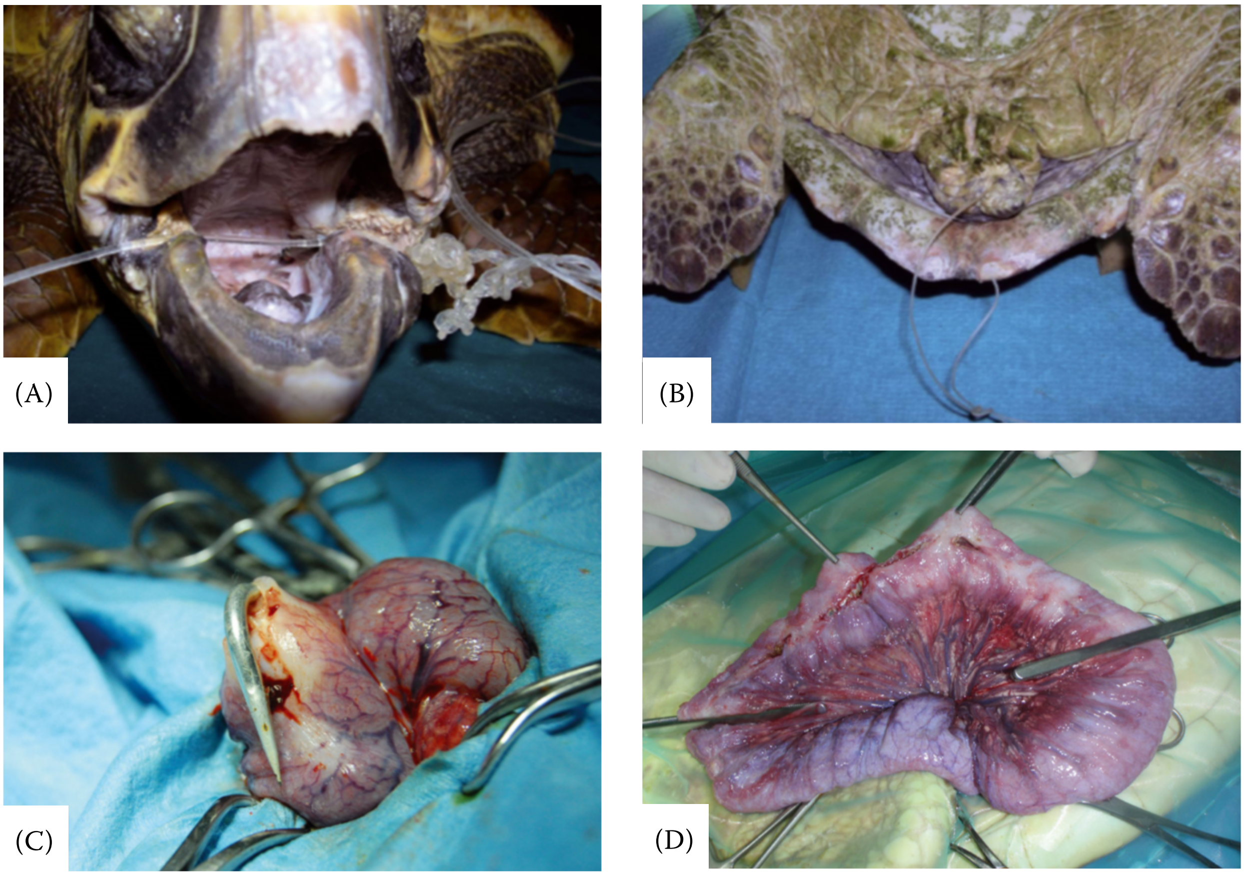

Figure 2. Loggerhead sea turtle with a fishing line protruding from its mouth (A) and cloaca (B). (C) Stomach exteriorisation for the extraction of a large hook perforating the gastric wall. (D) Intraoperative photograph showing the severe laceration of the intestinal wall caused by a fishing strand

Source: Modified Di Bello et al. (2013)

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buoyancy. This can lead to poor health, reduced growth and reproduction rates, and even death (Nelms et al. 2016).

The waste ingested by sea turtles originates from various sources. Plastics, glass, fishing artifacts, paper, microplastics, and metal, among other types waste material, are most often found in the stomachs of turtles (Andrady 2011; Gall and Thompson 2015; Rizzi et al. 2019). Most waste ingestion incidents occur with plastic fragments of different types and colours (Table 1) (Lazar and Gracan 2011; Hoarau et al. 2014; Gall and Thompson 2015; Poli et al. 2015; Fukuoka et al. 2016; Clukey et al. 2017; Pham et al. 2017; Wilcox et al. 2018; Duncan et al. 2019; Rizzi et al. 2019).

Ischaemia, necrosis, and intestinal rupture are the most frequent digestive tract mucosal injuries associated with the ingestion of solid waste (Levitt and Bauer 1992; Jerdy et al. 2017). Secondary infections and death are consequences of these injuries. For example, the presence of the bacterium *Enterococcus faecalis* in the bladder, brain, intestines, kidneys, liver, lungs, and muscles of a loggerhead turtle with an oesophageal perforation caused by a fishing hook and intestinal intussusception caused by a nylon strand have been found. In this case, the oesophageal and/or intestinal lesions were the likely entry routes for the pathogen, and its presence in the organs and viscera suggested septicaemia as the main cause of the animal's death (Fichia et al. 2016).

Plastic ingestion, in addition to the physical and anatomical aspects, exposes animals to an additional source of toxins (Teuten et al. 2009; Andrady 2011). Following the ingestion of plastics, chemical additives and persistent bioaccumulative and toxic chemicals can be absorbed by the body (Engler 2012; Fossi et al. 2018). This further increases the load of pollutants on the individuals through their transfer from the prey to predators in the food chain (Eriksson and Burton 2003).

Pollutants cause harmful effects, including impaired physiological aspects, chronic stress, immunosuppression, and increased susceptibility to diseases (Aguirre et al. 1995). Studies in North Carolina (USA) involving *C. caretta* have demonstrated that organochlorine compounds accumulate in animal tissues, causing hepatotoxicity, immunotoxicity, reproductive toxicity, and weakening, and affect the neurological behaviour (Keller et al. 2004). Saeki et al. (2000) and Fujihara et al. (2003) identified high concentrations of arsenic in both the liver and muscles in *E. imbricata*, *C. caretta*, and *C. mydas.* Acute arsenic intoxication can lead to gastrointestinal disorders, and ultimately, neurological problems (Gontijo and Bittencourt 2005).

Table 1. Percentage of frequency of occurrence (%F) and wet mass (%mass) of different types and colours of artificial debris in the gut and faeces samples obtained at the Sanriku Coast

Category	Loggerhead sea turtles				Green sea turtles			
	%F		%mass		%F		%mass	
	faeces (*n* = 28)	gut (*n* = 13)	faeces (*n* = 28)	gut (*n* = 13)	faeces (*n* = 25)	gut (*n* = 10)	faeces (*n* = 25)	gut (*n* = 10)
Type								
Hard plastic	3.6	15.4	2.0	3.1	16.0	30.0	0.3	0.6
Soft plastic	28.6	53.9	67.6	52.7	92.0	100.0	76.7	88.9
Styrofoam	0.0	30.8	0.0	44.1	20.0	30.0	1.3	0.6
Fishing line/rope	7.1	7.7	19.1	0.1	52.0	80.0	19.9	5.9
Rubber	0.0	0.0	0.0	0.0	4.0	40.0	0.1	0.4
Others	3.6	0.0	11.3	0.0	20.0	40.0	1.7	3.7
Colour								
Transparent	28.6	53.9	61.5	51.0	80.0	100.0	46.2	55.6
White	7.1	30.8	20.4	45.8	64.0	100.0	29.3	18.6
Black	3.6	0.0	11.3	0.0	64.0	70.0	10.3	6.5
Coloured	10.7	23.1	6.7	3.2	72.0	90.0	14.2	19.4

Source: Fukuoka et al. (2016)

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4. Imaging exams on sea turtles

Imaging exams can be used on sea turtles to identify alterations of the digestive tract, such as intussusceptions, impacts, obstructions, torsions, neoplasms, and foreign bodies, mainly due to the presence of anthropic waste (De Vico et al. 2003; Pressler et al. 2003; Di Bello et al. 2006; Valente et al. 2006; Valente et al. 2007a; Valente et al. 2007b; Erlacher-Reid et al. 2013; De Majo et al. 2016; Spadola et al. 2016b; Pease et al. 2017).

4.1 RADIOGRAPHY

Radiological examinations are used to detect the presence of anthropic residue in the digestive tracts of sea turtles, such as ingested metal hooks. However, it has limited abilities in identifying the internal organs due to the presence of the carapace and lack of visceral fat (Deshaw et al. 1996). Moreover, the low radiopacity of other foreign bodies, such as nylon strands and plastic bags, hampers its effectiveness. However, the use of a barium contrast may enable the identification of the points of obstruction (Figure 3) (Di Bello et al. 2006).

4.2 ENDOSCOPY, CLOACOSCOPY AND COLONOSCOPY

An endoscopy is a viable diagnostic technique in clinical practice for reptiles (Hernandez-Divers 2004; Spadola et al. 2016b; Franzen-Klein et al. 2020). The endoscopy of the upper digestive tract in sea turtles is relatively straightforward, since it allows the perfect visualisation of the oropharynx and glottis. However, the oesophageal path requires the extension of the neck of the animal and the inflation of the oesophagus with air to facilitate the passage of the endoscope as the oesophageal papillae resist its passage (Figure 4A).

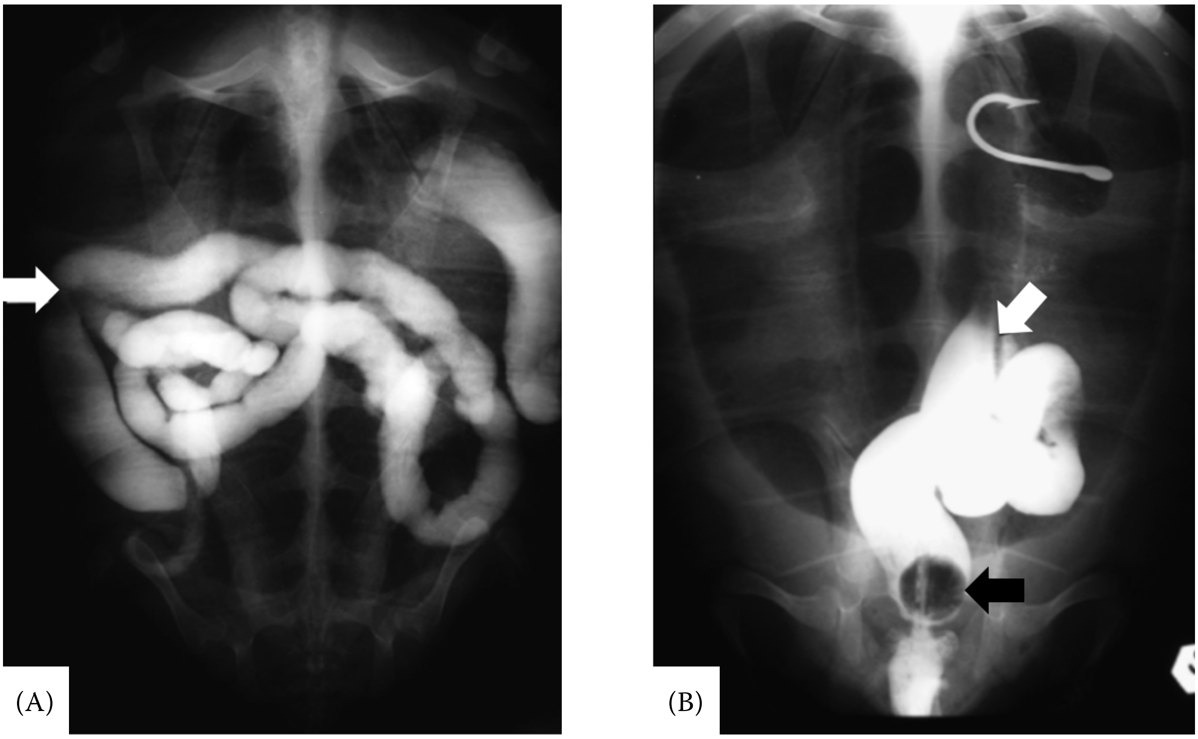

Figure 3. Contrast radiography of a loggerhead sea turtle's (*Caretta caretta*) digestive tract
(A) A dorso-ventral radiograph taken 48 h after the oral administration of a barium contrast. The residual contrast medium in the stomach and completely filled small intestine can be observed as the contrast medium progresses through the ileocolic valve (white arrow). (B) A dorso-ventral radiograph taken after an enema with a barium contrast. No retrograde progression of the contrast medium is shown due to the presence of a fishing strand attached to the fishing hook in the intestinal tract. A Foley probe is visible in the cloaca region (black arrow). The radiolucent line (white arrow) in the proximal extension of the contrast medium indicates the end of the thick nylon fishing strand
Source: Modified Di Bello et al. (2006)

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However, foreign bodies, such as hooks, which are radiographically identified, are not always visible in endoscopies as they are often lodged between the papillae. However, the gastroesophageal sphincter remains partially open and can be easily utilised by the endoscope, allowing the complete visualisation of the gastric mucosa (Figure 4B) (Pressler et al. 2003).

A cloacoscopy was first described by Coppoolse and Zwart (1985) and has since been rapidly adopted by reptile specialists. A cloacoscopic analysis of sea turtles allows the visualisation of different organ systems, such as the gastrointestinal, reproductive, and urinary systems (Figure 5). The term colonoscopy is used when the exam is performed on the colon segment. It is a valuable technique for

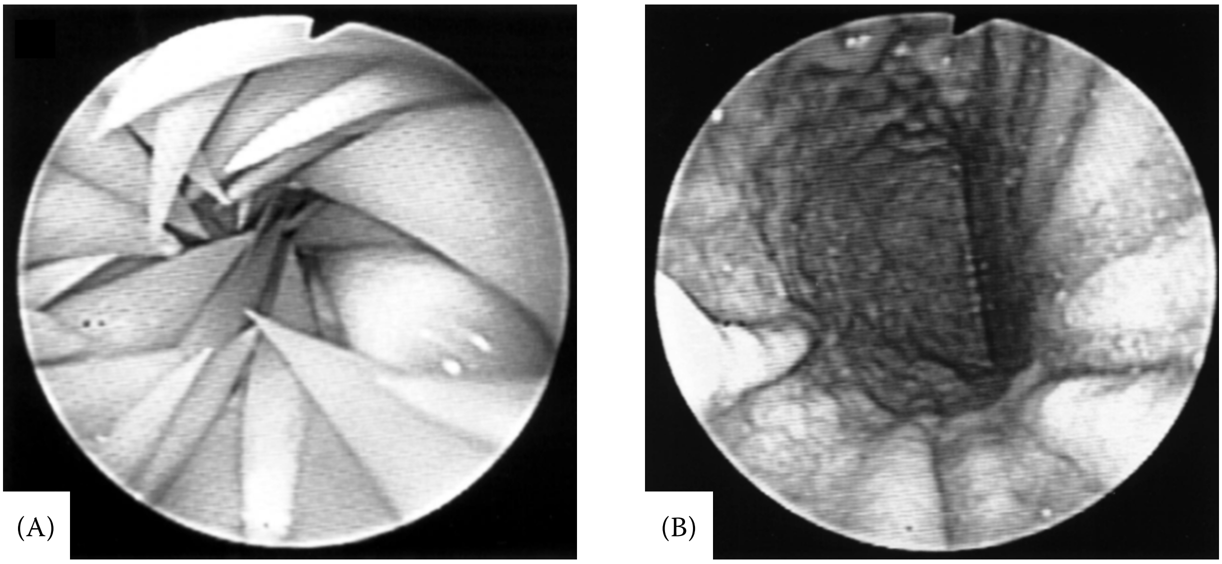

Figure 4. Endoscopy analysis of a loggerhead turtle (*Caretta caretta*)
(A) Endoscopic view of the oesophageal papillary region. (B) Endoscopic view of the gastric lumen and pylorus, visible from a distance
Source: Pressler et al. (2003)

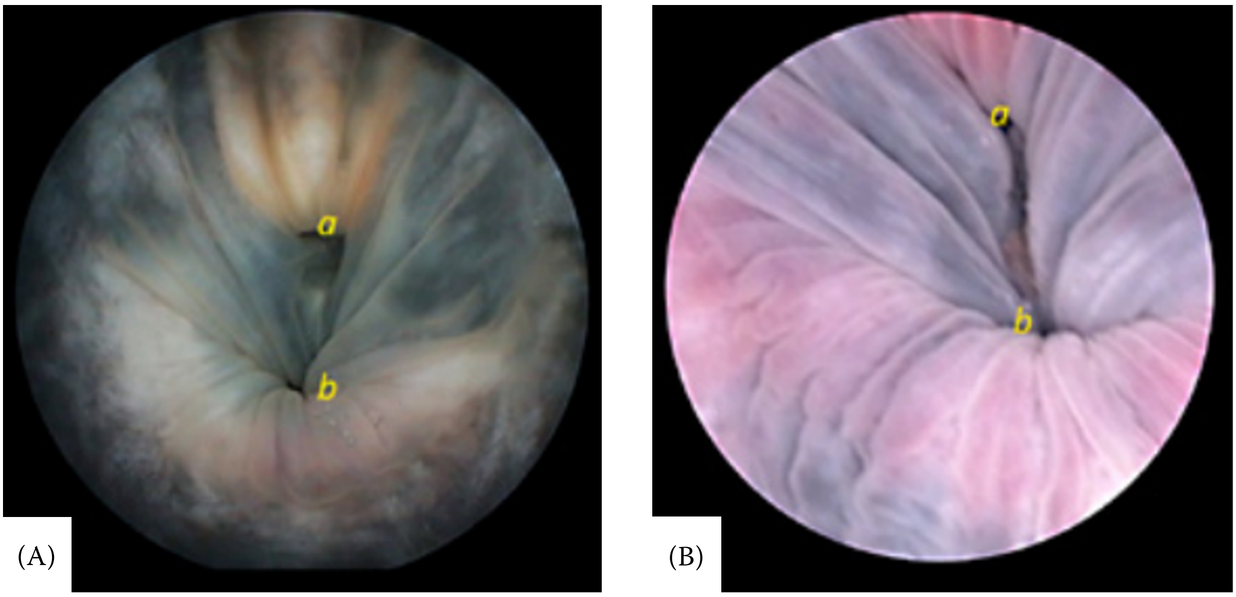

Figure 5. Cloacoscopy of the coprodeum and urodeum after an infusion of sterile saline in a loggerhead sea turtle (*Caretta caretta*). (A and B) The lower part of the image refers to the dorsal part of the animal. Observe the urodeum area (A) and the colon distal sphincter (B) in the adult female
Source: Spadola et al. (2016b)

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acquiring clinical information in cases of intestinal stenosis (Erlacher-Reid et al. 2013). Moreover, if any accessible foreign body, such as fishing strands, is present in the cloaca, the colonoscopy enables its removal in a minimally invasive manner (Figure 6) (Pressler et al. 2003; Spadola et al. 2016b).

4.3 ULTRASONOGRAPHY

Ultrasonography is a useful tool for the diagnosis of abnormalities of the digestive tract in juvenile and sub-adult sea turtles. It is cost-effective, safe, and straightforward to perform. This method can be used to examine most internal organs (Valente et al. 2007b; De Majo et al. 2016; Franzen-Klein et al. 2020) and for the diagnosis of intussusceptions (De Vico et al. 2003; Leiria et al. 2016; Bercier et al. 2017). The stomach of sea turtles is commonly visualised through the left pre-femoral acoustic window (Figure 7A), while the small and large intestines can be viewed from both the left and right pre-femoral acoustic windows (Figure 7B) (De Majo et al. 2016; Franzen-Klein et al. 2020).

4.4 COMPUTED TOMOGRAPHY (CT)

CT is a rapid and feasible imaging method for the clinical examination of sea turtles (Oliveira et al.

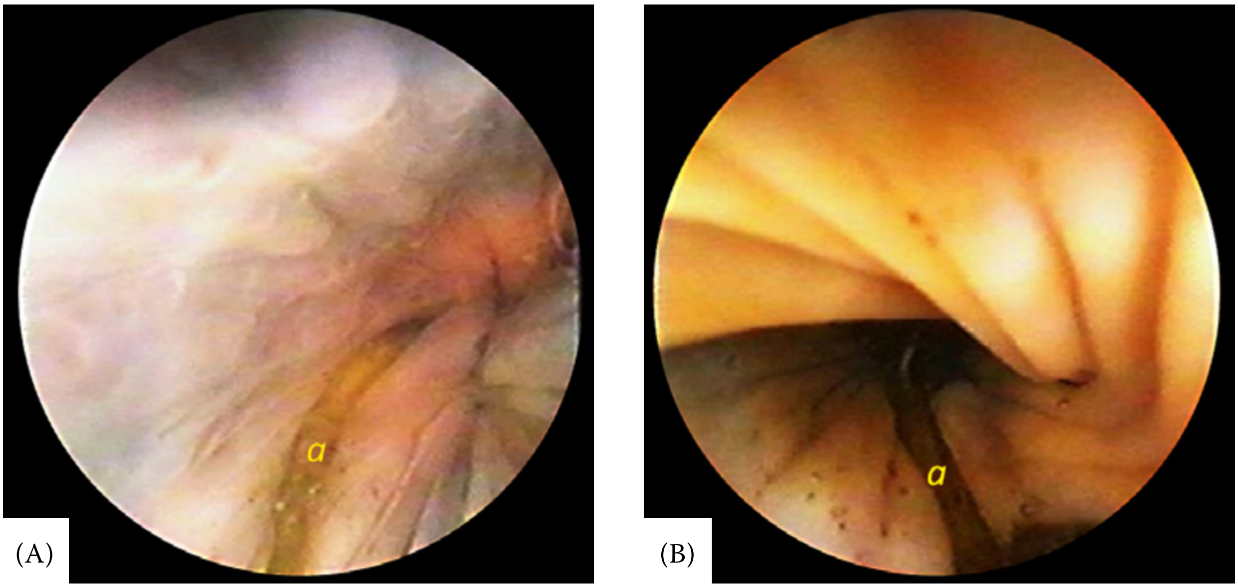

Figure 6. Cloacoscopy analysis of a loggerhead sea turtle (*Caretta caretta*)
(A and B) Fishing strands (A) can be seen in the distal colon
Source: Spadola et al. (2016b)

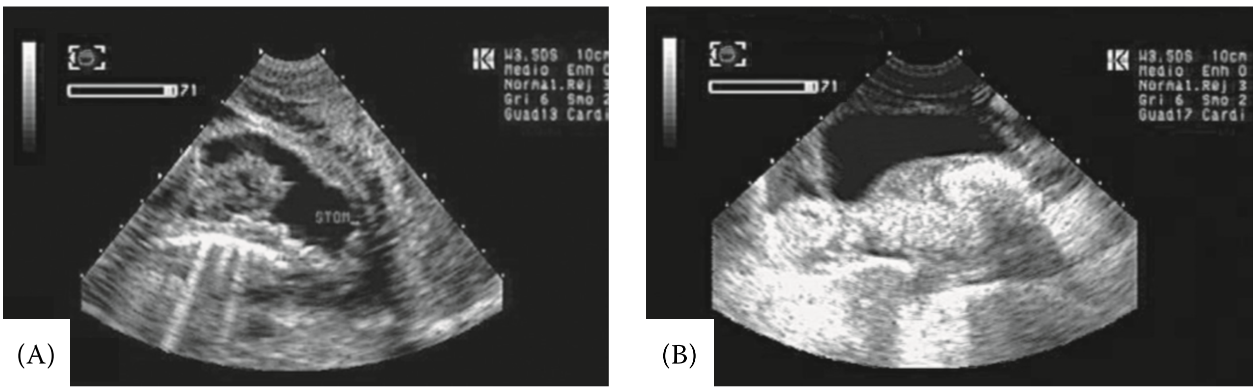

Figure 7. Ultrasonography analysis of a loggerhead sea turtle (*Caretta caretta*)
(A) Stomach: Gastric material. (B) Colon: Presence of gas with hyperechoic content, along with acoustic shading
Source: De Majo et al. (2016)

https://doi.org/10.17221/50/2020-VETMED

2012; Spadola et al. 2016a), as shown in a study reporting an intestinal mass in a green turtle (Figure 8) (Erlacher-Reid et al. 2013).

In this method, an iodine contrast medium can be used to increase the contrast between the normal structures and pathological tissues and to turn the vascular structures opaque (Caldmeyer and Buckwalter 1999).

Despite its high costs, the use of CT may reduce the treatment time, maximise the chances of successful rehabilitation, and consequently, reduce the cost associated with keeping the animal in captivity (Valente et al. 2007a; Erlacher-Reid et al. 2013; Spadola et al. 2016a). Therefore, CT is a valuable non-invasive method for the clinical examination of sea turtles in the rehabilitation process (Spadola et al. 2016a).

4.5 MAGNETIC RESONANCE IMAGING (MRI) OR MAGNETIC RESONANCE TOMOGRAPHY (MRT)

Compared with the other diagnostic imaging tools, MRI offers many advantages. Because no ionising radiation is used in MRI, it is not dangerous for the patients or technical personnel (Schreiber et al. 2001). It is a powerful technique for obtaining soft tissue images in several planes without repositioning the animal (Dennis 1995; Valente et al. 2006) and allows the visualisation of the blood vessels without the need for a contrast medium (Tucker and Gavin 1996). However, the data analysis takes longer compared to other techniques, and the sedation of or administration of anaesthesia to the animal is usually required. MRI is expensive compared to other imaging techniques. However, its use can be justified when treating endangered species, as it collects a significant amount of diagnostic information in a relatively short period of time with little risk to the animal (Walzer et al. 2002; Thornton et al. 2005; Valente et al. 2006).

Because the viscera of chelonians are completely covered by bone structures (carapace and plastron), the use of MRI to visualise and evaluate celomic structures has several advantages over other conventional imaging techniques. These include the representation of detailed cross-sectional anatomical features without distractions from overlapping structures, variations in grayscale formats, enhanced contrast resolution, and the computer reconstruction of multi-plane images (Figure 9) (Rubel et al. 1994; Valente et al. 2006).

Generally, digital radiography is the first choice for diagnostic imaging examination because it is widely available and less expensive than other techniques. Moreover, this method provides important information in many cases (Helmick et al. 2000; Di Bello et al. 2013). If a clinical diagnosis is subsequently available, the animal can be treated according to a veterinarian's recommendations, and there is no need for further exams. However, if the diagno-

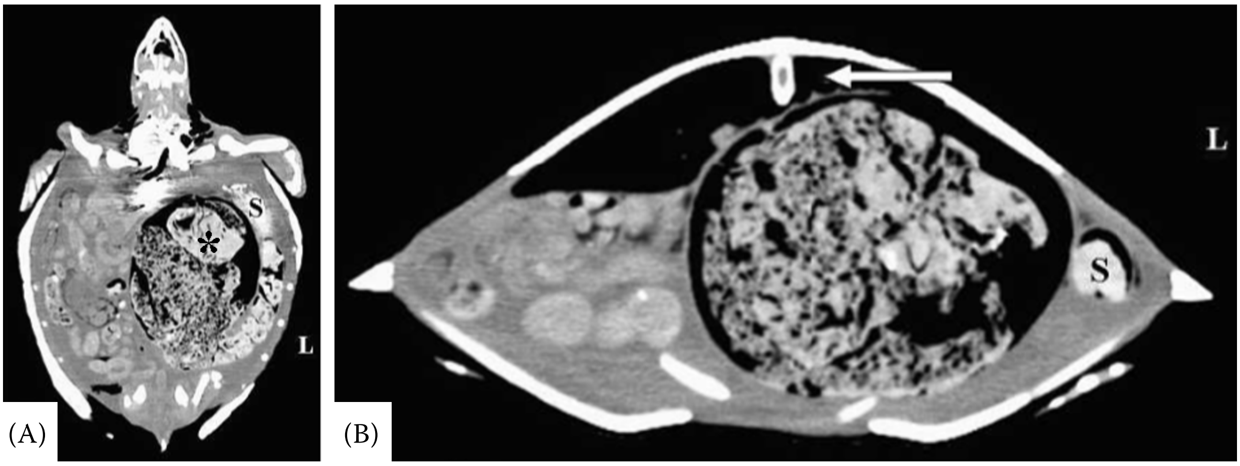

Figure 8. Helical computed tomography of a green sea turtle (*Chelonia mydas*)
(A) In the dorsal plane, a large intestinal mass, impaction, or foreign body is predominantly present in the dorsal plane and on the left side of the celomatic (*) cavity, displacing the stomach (S) to the left. (B) An intestinal mass, impaction, or foreign body measuring 8.7 cm in diameter is shown in the cross-sectional plane, displacing the left pulmonary lobe (arrow) dorsally and the stomach (S) to the left
Source: Modified Erlacher-Reid et al. (2013)

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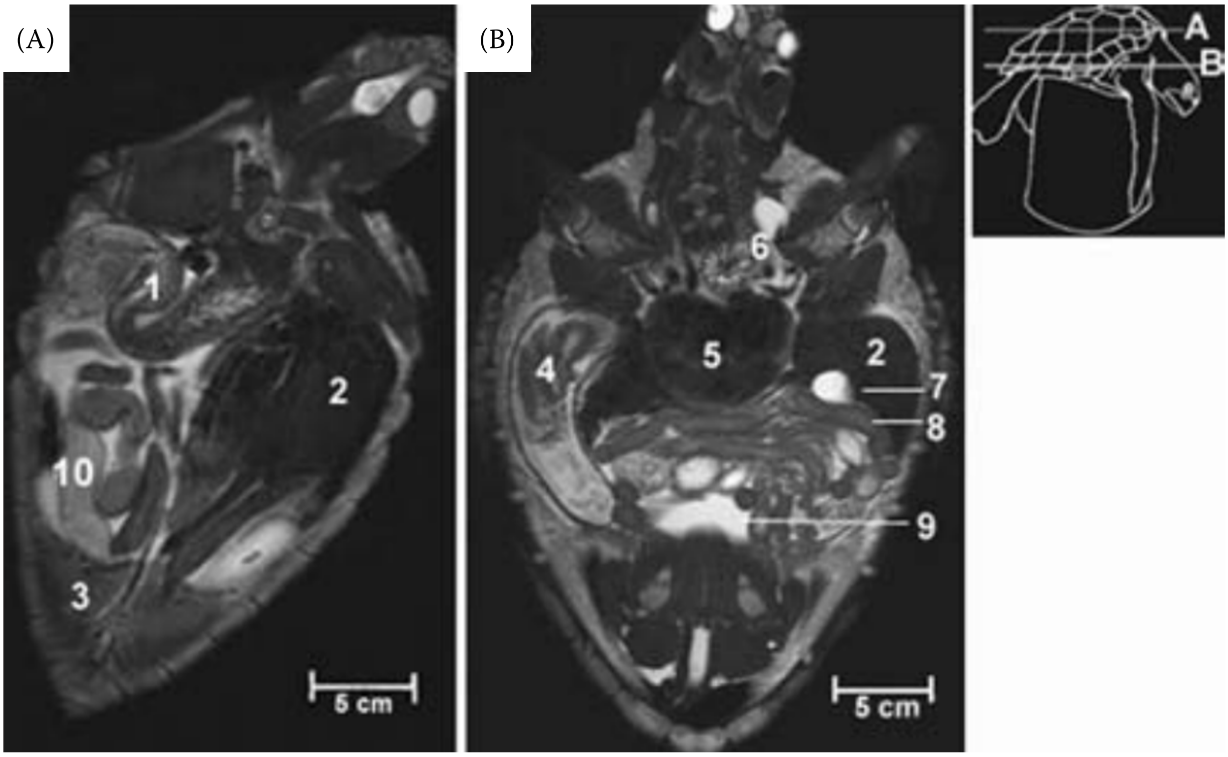

Figure 9. T2-weighted dorsal magnetic resonance images of the celomatic cavity of a live loggerhead turtle at different carapace levels (A and B)

Cardiac sphincter (1), liver (2), kidney (3), stomach (4), heart (5), oesophagus (6), gall bladder (7), duodenum (8), urinary bladder or celomic fluid (9), and descending colon (10)

Source: Valente et al. (2006)

sis is doubtful, the use of other tools, such as digital contrast radiography, ultrasonography, endoscopy, or cloacoscopy, should be considered, depending on the results of the clinical evaluation (Pressler et al. 2003; Di Bello et al. 2006; De Majo et al. 2016; Spadola et al. 2016b). Similarly, if a conclusive diagnosis is made by appropriate tests and tools, further exams may not be necessary. Otherwise, more complex and local exams, including CT or MRI, can be conducted based on their availability (Valente et al. 2006; Williams et al. 2013). A schematic diagram for the decision-making with regard to the choice of diagnostic methodology is provided in Figure 10.

5. Pathological findings in the digestive tract through imaging exams

Williams et al. (2013) reported a case where a loggerhead turtle accidentally ingested two rubber stoppers from a water heater in its enclosure. The radiographs initially taken were inconclusive. Subsequently, CT was used, and the ingested items were identified based on their shape and size. Further, a partial obstruction was observed in the region where the objects were located. The animal was treated with a mineral oil-based medical therapy, and a tomographic examination was repeated after two weeks; this identified a persistent partial obstruction. However, the displacement of the rubber stoppers through the intestinal tract was observed, allowing the authors to conclude that the continued treatment was adequate, since the foreign bodies were expelled in the faeces 26 days after their ingestion.

Franzen-Klein et al. (2020) reported six cases of foreign body obstructions in sea turtles, which were diagnosed using different advanced imaging modalities. Pre-femoral ultrasonography was used to correctly diagnose a monofilament fishing line linear foreign body obstruction in a juvenile female Kemp's ridley sea turtle (*L. kempii*) and a subadult female loggerhead sea turtle (*C. caretta*). The administration of an iodinated contrast confirmed a complete upper gastrointestinal obstruction in a juvenile green sea turtle (*C. mydas*). The traditional radio-

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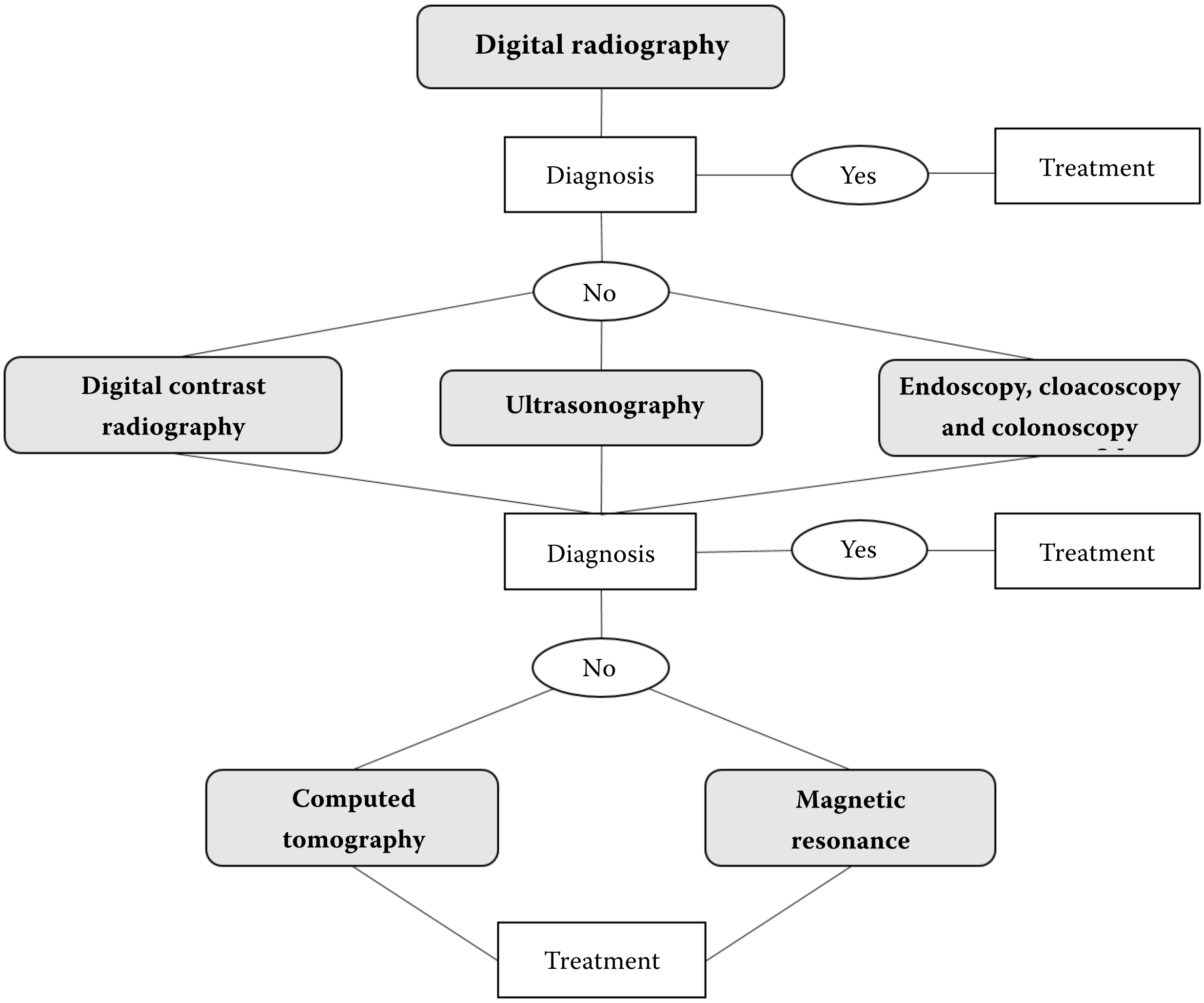

Figure 10. Decision-making flowchart for the digestive tract imaging examinations of sea turtles
Source: Own processing

graphs were non-diagnostic in all three animals. Barium-impregnated polyethylene spheres were used to identify a partial gastrointestinal foreign body obstruction in a juvenile green sea turtle. An endoscopy was used in multiple cases as both a diagnostic and therapeutic tool.

A case of an intestinal volvulus in a green sea turtle was reported by Helmick et al. (2000). Based on the radiography, the authors confirmed the gaseous distension of the animal's intestinal loops, suggesting an intestinal obstruction. Subsequently, the animal was admitted for surgery; during the procedure, an intestinal stenosis was observed at the site of the volvulus. After resection of the abnormal intestine, a leiomyoma associated with the focal stenosis was confirmed by the histopathological examination. Six months after surgery, the turtle recovered its normal buoyancy pattern and showed no further clinical signs of a gastrointestinal obstruction, as evidenced by a normal appetite and defecation.

Other cases have reported intestinal or cloacal stenosis resulting in intestinal obstructions in six green sea turtles. The aetiologies of the stenoses were unknown in these cases. The common abnormalities observed following the radiological imaging among most of these animals included constipation, enlarged intestines, and the accumulation of the oral contrast material. A lower gastrointestinal contrast radiography combined with the oral contrast was useful for identifying the suspected area of intestinal obstruction in two cases. A colonoscopy was crucial to visually diagnosing an intestinal stenosis in one case. A diagnosis was achieved in two cases

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through CT. In both cases, the colon was distended and linear soft tissue attenuation was present, suggesting oedema and inflammation of the intestinal loop. In one case, the MRI enabled the detection of a significant increase of the cloacal and intestinal dilation near the right and left kidneys (Erlacher-Reid et al. 2013).

Cases of intestinal intussusception have previously been reported in loggerhead (De Vico et al. 2003; Fichia et al. 2016) and green sea turtles (Oliveira et al. 2020b), with a partial or total obstruction being the most commonly reported consequences of this disease (Levitt and Bauer 1992). A permanent blood vessel obstruction resulting from the intussusception is related to ischaemia and necrosis, which are the determining factors for the development of late gastrointestinal perforations and ruptures (Patsikas et al. 2005). Although all intestinal portions can be affected, the incidence of such obstructions occurring in the ileocolic segment is higher than that of those occurring in the other portions in both animals and humans (Levitt and Bauer 1992; Wosar and Lewbart 2006; Batista and Maximiano 2009). Predisposing factors are often associated with gastroenteritis, parasitic infection, and foreign bodies (Macphail 2002). However, the presence of anthropic waste (nylon strands, hooks, plastic bags, and hard plastics) in the digestive tract of sea turtles is commonly reported as the main reason for the intussusception (De Vico et al. 2003; Oros et al. 2004). However, the diagnosis of an intestinal intussusception in sea turtles is relatively limited due to the frequent absence of clinical signs in the afflicted animals. However, ultrasonography and contrast radiography can be used as suitable imaging exams (De Vico et al. 2003; Di Bello et al. 2006).

Croft et al. (2004) investigated the effectiveness of MRI and radiography in the detection of internal tumours in 10 green turtles. Radiography was found to not be efficient in identifying tumours in the digestive tracts of these animals, but could identify tumours of the lungs. However, the MRI was able to detect tumour masses in the stomach of one animal and in the bladder, kidneys, and lungs of other animals.

6. Conclusions

Despite the low radiopacity for most foreign bodies, such as nylon strands and plastic bags, digital radiography remains a very useful tool for identifying solid waste with high radiopacity, such as hooks and rigid waste.

The use of a barium contrast makes this method even more efficient and even allows the obstruction points of the whole digestive tract caused by the presence of low-radiopacity residue to be identified.

Endoscopies and cloacoscopies are less invasive methods, the former being used mainly in the initial segments of the digestive tract, such as the oral cavity, oesophagus, and stomach, while the latter is useful in investigations of the caudal region, rectum, and cloaca.

Ultrasonography is efficient in identifying inflamed areas of the digestive tract and in diagnosing intussusceptions. It can also identify the accumulation of gases and other contents in the intestinal loops, which may indicate possible points of obstruction.

CT and MRI, despite their high costs, are the exams of choice for identifying not only rigid tissues, but also changes in soft tissues in the digestive tract, especially those related to abscesses and neoplasms.

Therefore, the diagnostic imaging exams demonstrate their importance in preservation medicine, as they can indicate the type of material ingested as well as its location, thereby allowing the appropriate decision-making for an animal's treatment.

However, the methodology to be used by a specialist depends on the suspected diagnosis as well as the financial and logistical conditions of a case. It is noteworthy that no imaging exam discards the need for a good anamnesis as well as evaluations using auxiliary exams, such as haemograms and serum biochemistry.

Acknowledgement

We would like to thank the Federal Rural University of Semi-Árido (UFERSA) and the Coordination for the Improvement of Higher Education Personnel – Brazil (CAPES, Financial Code 001) for the financing.

Conflict of interest

The authors declare no conflict of interest.

https://doi.org/10.17221/50/2020-VETMED

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Received: February 27, 2020
Accepted: October 26, 2020