Title: "Shell fracture in sea turtles: investigating stages of scarring (from a case study)"

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ABSTRACT:

In sea turtles, carapace fractures are commonly observed, and mostly caused by traumas. This dissertation will review the possibles surgical approaches to treat carapace traumatic injuries in sea turtles. To this aim we will also report and discuss a clinical case of a sea turtle that was rescued in El Hierro island, presenting multiple carapace fractures. The animal was moved to the La Tahonilla rescue centre; during a seven months long hospitalization, three different surgical techniques have been applied to treat the fractures. We will describe in details each surgical approach, including the cerclage, the application of epoxy resin with fiberglass cloth combined with screws, wire, and two splits, and the plates placement.

Moreover, changes in clinical condition as well as the response to the each treatment will be reported. The discussion will be mainly focused on the unexpected cicatrisation response observed in this animal; possible interpretation of the observed results will be provided.

INTRODUCTION:

Sea turtles are considered one of the oldest animals to have inhabited the Earth in modern times. Over the millennials, these creatures have maintained remarkable stability in their structure (Peter L. Lutz *et al.*, 2002). Modern sea turtles, as we currently know them, originated in the Cretaceous Period (around 120 million years ago) and they are the descendants of an ancient line of sea turtles (Spotila, 2004). Recent studies reported that there are approximately 327 known species of turtles which include freshwater sea turtles, marine turtles, tortoise and terrapins (Rodríguez *et al.*, 2018). Turtles can be found in different habitats on all continents except for Antarctica and in all the oceans except for the Artic (Flanagan, 2015). Nowadays, there are seven species of marine turtle living in the sea (Simantiris, 2024), classified in two of the four families of sea turtles that have survived from the ancient times (i.e., the Cretaceous Period) to the present, (Figure 1): *Cheloniidae spp.* and *Dermochelyidae spp.* Those two families are included in the largest order of Testudines.

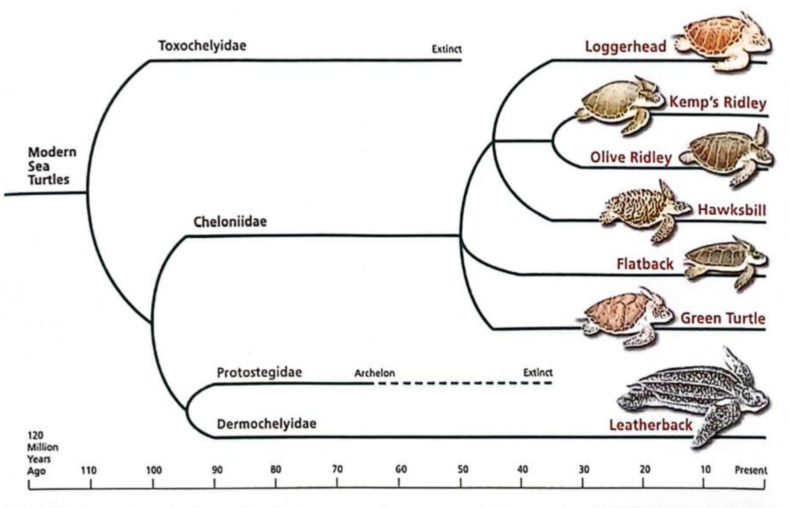

Figure1., Overview of the sea turtle descendent lines from the Cretaceous period to the present (Spotila, 2004).

Nowadays, only one species of sea turtle is included in the family of *Dermochelyidae spp.*, the Leatherback turtle, which is classified as the largest existing sea turtle (Paladino & Morreale, 2001). Concerning the family of *Cheloniidae spp.*, six different species are present. More specifically, they are divided into two suborders due to the differences in the cervicothoracic articulation, which will be described in detail in the following paragraph about the anatomy of the sea turtles. The first suborder is the *Cryptodirans*, which includes all the sea turtles that are characterized by the ability to draw the neck in a vertical direction in order to hide the head (Rodríguez *et al.*, 2018). Therefore, these sea turtles are called “hidden-necked turtles”. The second suborder is the *Pleurodirans*, which includes the sea turtles that are characterized by a different movement of the neck that is in a lateral direction instead of a vertical one (Wise & Stayton, 2017). Therefore, these sea turtles are called “side-necked turtles”. The species included in the family of *Cheloniidae spp.* are: Loggerhead (*Caretta caretta*), Kemp’s ridley (*Lepidochelys cempii*), Olive ridley (*Lepidochelys olivacea*), Hawksbill (*Eretmokelys imbricata*), Green (*Chelonya midas*) and Flatback (*Natator depressus*) turtles. (Manire *et al.*, 2017).

Concerning the anatomy of these animals, the skeleton of sea turtles has a bony and a cartilaginous component and it can be divided into three main parts: the skull, and the axial and appendicular skeleton (Figure 2) (Lara-Uc Ma. Mónica, 2015).

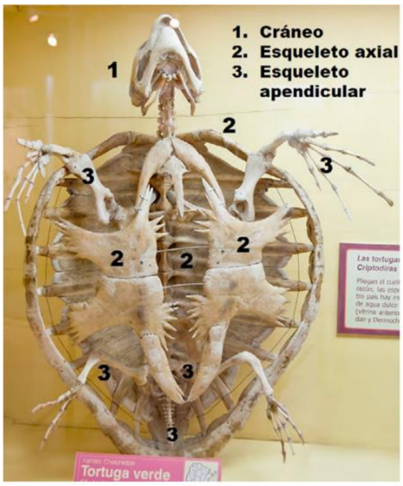

Figura 4. Esqueleto de una tortuga verde tomado de las Fotos de la colección de la sala de REPTILES del Museo Argentino de Ciencias Naturales Bernardino Rivadavia. Infografía: María Mónica Lara Uc.

Figure 2.: Overview on the anatomy of the sea turtle.

The skull is composed by a variety of compact bones which, based on their configuration, i.e., the disposition of the plate bones, are used for the identification of different species (Lara-Uc Ma. Mónica, 2015).

The axial skeleton is primarily composed by an external structure, i. e. the shell, that is composed by more than fifty different dermal bones (Gilbert *et al.*, 2001). The shell is a fundamental structure in sea turtles' everyday life, as it protects the vital organs (Lara-Uc Ma. Mónica, 2015). The shell is also the most recognizable element from an anatomical point of view. The shell, is composed by the carapace, in the dorsal position, and the plastron, in the ventral position (Rodríguez *et al.*, 2018). These two anatomical structures are jointed laterally by hard shell plates, including: i) the bridge, that is a cartilaginous connective tissue that permits, to some extent, the body expansion in a vertical direction so that this animal can breathe (Lara-Uc Ma. Mónica, 2015), and ii) the epidermal stratus that consists of sixteen scutes in the plastron and thirty-eight scutes in the carapace. In particular, the carapace consists of interconnected bony plates originating from flattened and expanded fused ribs that include the fixed vertebral column from the first thoracic to the coccygeal vertebrae (Rodríguez *et al.*, 2018).

The appendicular skeleton includes the fins, the rear ends and the structures that support them, which include: -the pectoral girdle and the pelvic girdle (Lara-Uc Ma. Mónica, 2015). Importantly, this part of the skeleton presents a typical structure that represents a marked difference between sea turtles and other reptiles. Indeed, in the sea turtles, the shoulder and pelvic bones are located inside the ribs and ventral to the vertebrae (Peter L. Lutz *et al.*, 2002).

Damages in sea turtle's skeleton might have a dramatic impact on their cavity and health conditions, therefore appropriate techniques for their treatment and recovery have been implemented, by considering the specificities of each species. The Loggerhead sea turtle (*Caretta caretta*), for example, is a common inhabitant of the sea surrounding the Canarias. As an endangered species, its conservation also involves the protection of nesting sites, where juveniles and adults are often captured by fisheries. In this context, significant threats to sea turtle populations also include environmental issues, including loss of habitat, and contaminant exposure, and physical issues, including marine debris ingestion or entanglement, fishery, and boat strike that can injure the sea turtles. The latter group of injury is the one most commonly affecting live stranded sea turtles. When sea turtles are carried out to recovery centres, they commonly have skin and shell wounds caused by traumas such as boat strikes, shark bites, fishing gear entanglements, entrapment in dredging equipment, dropping on a boat deck after incidental capture, and wounds developing secondary to cold stunning. Indeed, trauma caused by collisions may result in crushed tissues, haemorrhage in the head, carapace and plastron fractures and even flipper amputation. The planning of the most appropriate intervention to treat these wounds is critical for sea turtles' survival, as fracture instability and the likelihood of subsequent system infection development, can cause weakness, disorientation and secondary infectious diseases in the lungs and kidneys, and often result in death (Domiciano *et al.*, 2017).

Before specifically illustrating the possible surgical resolutions of an injury or fracture in sea turtles, it is essential to dedicate a few lines to explaining the basic protocol to follow when receiving an injured wild sea turtle. Typically, the live stranded sea turtles are confined in a sturdy container with foam padding and transported in a temperature-controlled vehicle and carried out to the closest recovery centre. As soon as the animal is welcomed into the recovery center, or if it is possible to work on the site where the injured sea turtle was found, the operators perform thorough history, visual examination, and detailed systematic physical examination, which include the assessment of body weight, bloodwork, if the condition of the animal are not very compromised (Chittick *et al.*, 2003), and standardized morphometric measurements. The standard measure of carapace length for the Cooperative Marine Turtle Tagging Program (CMTTP) is the straight carapace length notch to tip (SCLn-t) measured from the anterior point at midline (the nuchal scute) to the posterior tip of the supracaudals. Since the posterior tips of the supracaudals are frequently broken in juveniles or worned away in adults, the minimum straight carapace length (SCLmin; also referred to as SCLnotch-notch), measured from the anterior point at midline (the nuchal scute) to the posterior notch at midline between the supracaudals, is recommended as the standard measurement in the Marine

Turtle Specialist Group (MTSG) techniques manual (Eckert *et al.*, 1999). A clear understanding of the normal anatomy is therefore critical in sea turtle medicine and surgery.

Digital images represent an important instrument to document specific lesions or injuries in the carapace and in the plastron and to establish the correct treatment, prior to any surgical approach. Indeed, sea turtles might show poor clinical signs, therefore a physical examination might benefit from the use of complementary diagnostic procedures (Penninck *et al.*, 1991), such as radiological examination (Silverman et al., 1989; Penninck et al., 1991; De Majo et al., 2016)), that can detect the presence of a swallowed fishhook and assess shell lesions. Along with radiography, computed tomography (CT) is useful for assessing spinal and head injuries, while ultrasonography has been used to evaluate reproductive status and for general diagnostic purposes, including intestinal obstruction, and motility disorders (De Majo et al., 2016)

The treatment of shell wound requires the application of basic principles of wound care, such as debridement and heavy irrigation with sterile saline solution. This preliminary work represents a necessary step because, in the presence of such damage, the injured area is often contaminated by the presence of dirt or water. An accurate and deep cleaning of the affected areas is a very important step to limit or even completely prevent contamination of the fracture site, and in case of a deep lesion, that the fracture could cause an opening of the coelomic cavity, and the consequent contamination of lungs and/or organs that are present in the compromised cavity. The administration of a preventive antibiotic therapy is also indicated, to control for possible contamination of the fracture (Chittick *et al.*, 2003). In case that the shell is an involved part of the injury, it is also possible to stabilize the fragments of the fracture by using cerclages or a support bar (Flanagan, 2015). At the same time, as most sea turtles presented for emergency care are dehydrated, hypoglycaemia or hyperglycaemia is common, so nutritional support is provided in combination with the therapy. Captive sea turtles feed a high quantity of thawed fish, that is rich of thiaminase, the enzyme that metabolizes thiamine, accumulated during the slaw thawing, in case of an animal is hospitalized for long periods, it is important to supplement thiamine in combination with the therapy (Doneley *et al.*, 2018). Waterproof bandaging techniques are commonly used, but topical wound care products based on silver-containing products, natural honey and sterile honey products are also successfully used in sea turtles' care. For example, products used to pack into deep wounds include silver sulfadiazine cream (Kings Pharmaceutical, Bristol, Tex) mixed with ilex paste (Medcon Biolab Technologies, Grafton, Mass) and honey mixed with honeycomb. When possible, a combination of waterproof tape, and super glue is used to create a watertight bandage. In areas that are difficult to bandage, suture loops may be placed around the wound with umbilical tape placed through the suture loops and tied together to hold the bandage materials in place. Otherwise, bone cement impregnated with antibiotics could be used on the exposed shell bone, providing an excellent coverage of wound and protecting it in the water also without a bandage (Norton, Terry M., 2016) It is also recommended, if the condition of the animals permits the procedure, to put an intravenous catheter to permit a blood examination or to administrate treatment or fluid therapy in case of emergency (Chittick *et al.*, 2003). There are different prognosis levels going from excellent (a closed, stable, single fracture) to grave (multiple comminute fractures with a 30% of missing shell fragments). This classification depends on the condition of the animal in the moment of the rescue, on the amplitude and localization of the fracture, and on the fact that is a close or an open fracture. Accordingly, this classification is a useful tool to choose the correct kind of treatment (Fleming, 2008). If the injury, for example, affects the vertebral column, the animal is less likely to recover, due to the damage to the spinal cord. At the same time in case of deep fracture of the shell, also the lungs and/or the coelomic cavity could be affected and endanger the sea turtle's recovery and survival (Rodríguez *et al.*, 2018). Importantly, in case of lung damage, it is important to consider that these animals do not need a negative pressure in the coelomic cavity to continue breath, so this kind of injury will not affect their respiratory capacity (Rodríguez *et al.*, 2018). The prognosis is worst if the animal is depressed and, does not react to stimulation, and if it is unable to support itself in the water and to eat enough (Franchini *et al.*, 2023). The therapy typically starts with the administration of an analgesic protocol based on Butorphanol. After the stabilization of the patient and after getting a diagnosis, if this could be established, if the injury required a surgical solution, an anaesthetic protocol must be established. It can include Medetomidine, that can be administrated intravenous to induce a regular induction, or Ketamine that can be administrated also through intramuscular injection. The maintenance of the anaesthesia can then be sustained using Isoflurane or Sevoflurane (Chittick *et al.*, 2003). The choice of the correct treatment of a shell fracture depends on the characteristic of the lesion, on the animal living condition, and on the location of the fracture. The epoxy resin with fiberglass can be used in non-displaced fractures or in case of plastronotomy closure. In case of a displaced fracture, external fixation like screws, wire, plates, and external fixater rods, could be applied (Fleming, 2008).

Objective:

The goal of this dissertation is to provide an overview on the major causes of carapace injuries in sea turtles and on the surgical treatments available to support carapace treatment recovery. This will be supported by a case study that will present the clinical history of a *Caretta caretta* sea turtle that presented carapace injury. In particular, this dissertation will describe its history from its arrival to the recovery centre and its surgical treatment, to its recovery and its final release to nature.

MATERIALS AND METHODS

Clinical features of the sea turtle:

The sea turtle was found from a fisherman in El Hierro Island, in the town hall of "La Restinga" on the 28th of April 2022. The patient presented a complex fracture, that comprised the cranial aspect of the carapace, which was lesioned in multiple locations. The 29nd of April the sea turtle was moved to the rescue centre of "La Tahonilla", in Tenerife, and admitted for a seven months long hospitalization.

Figure 3.: The patient when being weighed upon entering the rescue center

The patient weighted 25 kilos (Figure 3), and the straight carapace length notch to tip was 52 cm; the curved carapace length notch to tip was 56 cm; the minimum straight carapace length was 44 cm, while the minimum curved carapace length was 52 cm (Eckert *et al.*, 1999). The following week the sea turtle, that arrived to the centre in compromised clinical conditions, was initially stabilized, but, due to the deplorable state, it was not possible to analyse and monitoring vital signs. To monitor the general health condition of the sea turtle, its weight was continuously measured since the admission. On the 29th of April, prior to the surgical treatment, deep debridement of the wound and surrounding tissue, including necrotic bone removal was performed. The Vets medicated the wounds with chlorhexidine. Antibiotic coverage was performed using a double treatment that consisted in Ganadexil (enrofloxacin, administered at a dose of 1.45 ml through intramuscular injection, every 12 hours), and Ceftimax (Ceftiofur, administered at a dose of 1.9 ml trough intramuscular injection every 24 hours). They also administered an analgesic treatment, consisting in Tralieve (Tramadol hydrochloride at a dose of 0,48 ml trough intramuscular injection). In the following days a regular assessment of the fracture's features, and of the wounds was performed. In particular, this assessment included the observation of their depth, the observation of the conditions of the residual tissues, and of the major neighbouring organs involved. To complement the physical assessment and the pharmacological treatment, two x-rays were performed on the sea turtle's carapace, from two different projections: the ventro-dorsal and the rostro-caudal (Figure 4), that confirmed a fracture of the shell, with the absence of part of it in the middle area, and the presence of pneumonia. The X-ray machine used in this case was an EPX-F2800 with values set at 42kVp and 10mA.

Figure 4.: Rostro-caudal projection of the X-ray.

After a detailed examination of the fracture, and its clinical treatment, the first surgical intervention to the carapace fracture was performed. Over the following three months, the patient underwent three different surgical interventions, using three different surgical approaches. The first surgical approach consisted in placing cerclages to reduce the fracture (Figure 5) (the surgical approach is reported in the "Different surgical approaches" paragraph)

Figure 5.: The patient after the cerclage surgery.

The day following the cerclage surgery, the wound suppurated, therefore, in addition to the administration of the pharmacological treatment started on the first day, the Vets introduced a treatment with fluid therapy in a 1:1 concentration of Ringer’s lactate solution and NaCl. Also, they chose to apply a silver plaster (antimicrobial) and to put a bandage on the wound.

On the 2nd of May the cerclages were removed due to the presence of necrosis in the fracture’s neighbouring tissues. Consequently, the Vets decided to remove the necrotic tissue, which also resulted in the removal of parts of the shell and bone, causing the widening of the distance between the fracture fragments. Due to this complication and the critical condition of the patient, the prognosis was declared as reserved. The treatment with Ceftimax and fluid therapy was continued over the following days, and the wounds were carefully cleaned daily, using chlorhexidine, betadine, and applying Furacin ointment (antimicrobial). Importantly, to support the repairing mechanisms, and, especially, to favour the cicatrisation of the carapace, on the

4th of May, the Vets decided to start laser therapy, using the K-Laser device. This approach was performed to stimulate the cells around the wound, and promote healing. (Figure 6). After the laser therapy, the wound was covered using Linitu dressings (medicated dressings impregnated with castor oil to promote healing). To assess the animal's appetite and state of activity, and consequently to verify the clinical condition of the patient, the animal was moved in a tank with water and food. In the same day, the sea turtle was successfully hydrated and fed, starting with a half sardine. The amount of food was gradually implemented during the time the patient was hospitalised, thus showing an improvement in clinical condition.

Figure 6.: Laser therapy session.

The medical treatments were unchanged in the following weeks, and they also included Vetramil in ointment, honey-containing product that promotes healing of damaged tissue, to promote recovery of the injured area. During its hospitalization, the Vets also started to supplement thiamine in combination with the therapy.

On the 18th of May, the Vets decided to perform another surgical intervention, the “Bridging Methods”, which consisted in the application of two splints of fiberglass cloth with epoxy resin, to reduce the distance between the two edges of the fracture (surgical technique is reported in the “Different surgical approaches” paragraph). (Figure 7)

Figure 7.: The patient after the “Bridging Methods “surgery

On the 23rd of June, the Vets decided to perform a further surgical intervention to further reduce the fracture. This consisted in applying titanium plates with polyaxial locking screws. (Figure 8) (surgical technique is reported in the “Different surgical approaches” paragraph). To proceed with the implantation of the titanium blocked plates, the patient was anesthetised with Propofol and the maintenance of the anaesthesia was achieved using Isoflurane.

Figure 8.: The patient during the titanium plate placement surgery

After the surgeries, the plaques were gradually removed in several steps, based on the patient clinical response (see the "Results" chapter). Simultaneously, the medical treatment and the daily cleaning of the wound continued until the animal was fully recovered. At the end of the hospitalization the animal developed a second intention cicatrisation, that permitted to release the sea turtle at the end of November.

Different surgical approaches:

1) **The cerclage:**

   In the clinical case presented in this dissertation, the Vets put three cerclages to reduce the fracture as a first surgical approach. They used a 1-millimetre-thick stainless maple cerclage wire (Braun). It is one of the simplest surgical techniques indicated for the resolution of fractures. Consists of making holes along the fracture site on both sides with an electric drill or Kirschner wire or a power tool. Once the holes were drilled, a Kirschner or cerclage wire was inserted and the ends were joined, facilitating the bringing together of the fracture fragments (Doneley *et al.*, 2018). This surgical approach can be used alone or combined with other fixation methods and it allows the treatment of the fracture site as an open wound (Flanagan, 2015).

2) **The "Bridging Methods"**

This approach is characterized by a combination of different material and techniques to achieve an adequate fracture reduction and repair. In the clinical case presented in this work the cement was combined with other fixation methods, including some screws, a cerclage wire and two splits. For turtles treated with the screws-and-wire technique, pilot holes were drilled partway through the dermal bone of the shell at least 0.5 cm from the fracture edge. The size and length of the screws used varied with the size of the turtle being treated. Sterile screws were inserted into pilot holes and advanced partially into the bone by hand with a screwdriver. Screws were then connected using surgical cerclage wire wrapped.

3) **Titanium plate placement:**

This surgical consisted in positioning a titanium plate "for large fragments", produced by biosurgex, a start-up of the "Instituto Tecnologico de Canarias" (ITC).. Due to the relevant size of the fracture, the Vet used three types of different locking plates used with 3.5 mm titanium locking screws for a total of six of the "Biosurgex 3.5 Locking Plate System" plates: four straight locked plates (thickness of 3.5 mm), one distal radius plate, and one supracondylar left femur plate. The straight plates were selected with different sizes, depending on the location, based on the fracture focus: the plate positioned closest to the head of the animal, the most cranial one, measured 125 mm, whereas the one located more caudally with respect to the fracture site measured 150 mm. The material of the plate was fundamental in the successful resolution of the surgery because the titanium permitted a corrected alignment of the plates so that they were anatomically adapted to the patient's carapace.

To perform the surgery, the Vets also needed specific materials such as a screwdriver, a drill bit, a depth gauge and a plate bander. The titanium plate placement technique is the most commonly used to reduce the size of the fracture, and to obtain a permanent shell stability, (Luis Crespo-Picazo *et al.*, 2013) by promoting a healing by second intention. Titanium plates are specifically useful in repairing plastron fracture due to the simple structure that permits the de-ambulation and the movement of the patient. Despite the many advantages that this surgical technique brings, the Vets must be careful as a large part of the fracture site is likely to be covered by the titanium plate, which, therefore could hamper the wound monitoring and care. (Doneley *et al.*, 2018).

RESULTS AND DISCUSSION:

The patient had lost 6,05 kg in the first week of its hospitalization in the rescue centre. However, aquatic chelonians are commonly anorexic during the treatment period (Fleming, 2008). When the Vets decided to remove the cerclage and add nutrition to start feeding the patient, the sea turtle started to appear more active and to manifest interest to the food. It was an important sign of a favourable prognosis.

1) The cerclage (Figure 9) caused an important necrosis reaction on the tissue surrounding the fracture site, therefore, the Vets were obliged to remove the wire and to carefully clean the fragments involved in the injury. This worsening could explain the animal's loss in weight and activity. It should also be kept in consideration that this condition delayed the healing process, because the Vets had to remove some more portions of the shell, thus leaving a greater distance between the edges of the fracture.

Figure 9.: The patient before (left) and after (right) the cerclage surgery.

2) The Bridging Methods approach (Figure 10) was characterized by a combination of different materials such as screws, wire, epoxy resin and two splints, that did not present the same degree of stabilisation as an orthopaedic repair. This method can be used with an

effective outcome in non-displaced fracture or as the preferred way in case of the closure of a plastronotomy (Portier *et al.*, 2022).

Figure 10.: The patient after the second surgery.

3) The titanium plate placement (Figure 11) was the most resolutive surgery in the clinical case presented in this dissertation. It was an invasive method, but it guaranteed a good and effective stabilization of the fracture. To obtain a successfully reduction of the fracture, it was very important to measure, to model end to cut the plate, to anatomically adapt it to the shape of the carapace of the patient so that it would not had hampered its movement. (Doneley et al., 2018). This probably represents the best resolution in case of a displaced plastron fractures (Fleming, 2008).

Figure 11.: The patient after the apposition of the titanium plates.

The patient might have encountered a boat strike, which notably is the most common reason of traumatic shell fracture in sea turtles. During the first week of the animal's stay at the recovery centre, it underwent a consistent decrease in weight, therefore hydration and an adequate nutritional support was implemented. This preliminary treatment primarily contributed to the improvement of the patient's physical condition and activity and supported the repair of the shell following the surgery. The cerclage was probably not effective following the patient weight loss that provoked the loosening of the cerclage and induced an irregular displacement of the scutes, and the exposure to debris, in proximity of the injury site. The removal of the resulting necrotic tissue that grew following the cerclage failure, on the one hand, slowed down the healing process, but, on the other hand, promoted the growth of new layers of keratin that by depositing along the seams between the scutes contributed to the recovery of the shell, that did not show any callus on the scar. This synthesis was supported by the bridging method approach. Indeed, the combination of different materials with different mechanical properties might have had promoted a more effective repair of the shell. Also, the improvement of the sea turtle's global health, due to hydration and nutritional supply, might have enhanced that production and release specific enzymes, such as the Alkaline phosphatase (ALP) that is present in the kidneys, which increase, notably, reflects bone remodelling, including shell production. Furthermore, the administration of vitamin A might have also prevented from hypovitaminosis A, which is known to induce squamous metaplasia, and, therefore, might have predisposed the accumulation of keratine in the damaged site. Indeed, with respect to the physiological functioning of the keratin scutes, they likely facilitate healing of the underneath bone that may be fractured by non-fatal assaults, enabling bone remodelling (Lyson *et al.*, 2013) under adequate physiological conditions (e.g., maintaining a physical barrier, preventing pathogen infection).

The peculiar feature of this clinical case consisted in the repairing processes, which differed from what the Vets expected. The patient showed a second intention cicatrisation, a physiological cicatrisation process that takes place when the extremity of the wound cannot be apposed. However, reparation processes in sea turtles are usually characterized by the progressive reconstruction of the carapace, which is a slow and complex process that may take up to a year (Flanagan, 2015). Differently, the second intention cicatrisation determines a scar tissue apposition in the wound, that occurs more rapidly, allowing its fast closure. Although unexpected, in this clinical case, the second intention cicatrisation occurred some weeks after the surgery, favouring a faster recovery and, consequently, an earlier release of the turtle. Normally, the turtle would have been hospitalized for a longer time, that would have been necessary for a complete closure of the carapace, as well as for the reepithelialisations of the original tissue (Flanagan, 2015). The occurrence of this process probably reflected the effect of one or more therapies administered to the animal. A possible hypothesis is that the laser therapy played a relevant role, supporting and improving the repairing mechanisms in the lesioned tissues. Healing time may take up to a year for bony bridging and this reaction was probably stimulated by the application of the laser therapy on the lesion borders. The mechanism of this clinical approach depends on the target and the type of cell being modulated. Low-Light Laser Therapy (LLLT) is a painless technique used to stimulate the natural biological process involved in healing tissues in order to obtain a faster cicatrisation, increasing vascularization and giving to the cells the energy to react and to produce the cicatrisation (Fesseha, 2020). Despite, the penetration of the laser light through the thick epidermis of reptiles and fish is currently unknown, the efficiency of the laser therapy was demonstrated in different clinical cases presented in zoological reptiles. (Dadone L., Harrison T., 2017)

CONCLUSIONS:

We conclude that in large reptiles the most effective surgical technique to approach extensive and multiple fractures consists in orthopaedic plates placement. Importantly, based on the described case, we also suggest that the laser therapy might play a relevant role in the cicatrisation process, by promoting an effective and faster recovery of the wound. Other surgical approaches, such as the cerclage, may be used before the plates placement to temporarily stabilise the fracture.

BIBLIOGRAPHY:

Chittick, E. J., Aczm, D., World, S., & Orlando, O. (2003). *EXOTICS-AQUATIC MEDICINE CONSIDERATIONS IN SEA TURTLE ANESTHESIA AND SURGERY*. https://cabidigitallibrary.org

Dadone, L., & Harrison, T. (2017). Zoological Applications of Laser Therapy. In *Laser Therapy in Veterinary Medicine* (pp. 320–333). Wiley. https://doi.org/10.1002/9781119220190.ch30

De Majo, M., Macri, F., Masucci, M., Coci, G., & Pennisi, M. G. (2016). Clinical ultrasonography in loggerhead sea turtles (Caretta caretta): Imaging of pathological features. *Veterinarni Medicina*, *61*(3), 155–161. https://doi.org/10.17221/8767-VETMED

Doneley, B., Monks, D., Johnson, R., & Carmel, B. (2018). *Reptile Medicine and Surgery in Clinical Practice*. http://www.wiley.com/go/permissions.

Eckert, K. L., Bjorndal, K. A., Abreu-Grobois, F. A., Donnelly, M., & Bolten, A. B. (1999). *Research and Management Techniques for the Conservation of Sea Turtles Techniques for Measuring Sea Turtles*.

Escobedo-Bonilla, C. M., Quiros-Rojas, N. M., & Rudín-Salazar, E. (2022). Rehabilitation of Marine Turtles and Welfare Improvement by Application of Environmental Enrichment Strategies. In *Animals* (Vol. 12, Issue 3). MDPI. https://doi.org/10.3390/ani12030282

Fesseha, H. (2020). *Laser Thrapy and its Potential Application in Veterinary Practice-A Review*. https://www.researchgate.net/publication/341322206

Flanagan, J. P. (2015). Chelonians (Turtles, Tortoises). In *Fowler's Zoo and Wild Animal Medicine, Volume 8* (pp. 27–38). Elsevier. https://doi.org/10.1016/b978-1-4557-7397-8.00004-9

Fleming, G. J. (2008). Clinical Technique: Chelonian Shell Repair. *Journal of Exotic Pet Medicine*, *17*(4), 246–258. https://doi.org/10.1053/j.jepm.2008.08.001

Franchini, D., Paci, S., Ciccarelli, S., Valastro, C., Salvemini, P., & di Bello, A. (2023). Clinical Findings, Management, Imaging, and Outcomes in Sea Turtles with Traumatic Head Injuries: A Retrospective Study of 29 Caretta caretta. *Animals*, *13*(1). https://doi.org/10.3390/ani13010152

Gilbert, S. F., Loredo, G. A., Brukman, A., & Burke, A. C. (2001). Morphogenesis of the turtle shell: the development of a novel structure in tetrapod evolution. In *EVOLUTION & DEVELOPMENT* (Vol. 3, Issue 2).

Lara-Uc Ma. Mónica. (2015). *Anatomía esquelética de tortuga marina*. https://www.researchgate.net/publication/288833942

Luis Crespo-Picazo, J., Martínez, V., Martins, S., Abella, E., López, P., García-Párraga, D., & Marco, A. (2013). Surgical repair of a large shell injury in a loggerhead sea turtle Caretta caretta and the need for a wildlife recovery centre in the Cape Verde Islands. In *Zoologia Caboverdiana* (Vol. 4, Issue 2). www.scvz.org

Manire, C. A., Norton, T., Stacy, B. A., Innis, C. J., & Harms, C. A. (n.d.). *Sea turtle health and rehabilitation*.

Paladino, F. v, & Morreale, S. J. (2001). *SEA TURTLES*.

Penninck, D. G., Stewart, J. S., Paul-Murphy, J., & Pion, P. (1991). ULTRASONOGRAPHY OF THE CALIFORNIA DESERT TORTOISE (Xerobates agassizi) ANATOMY AND APPLICATION. In *Veterinary Radiology* (Vol. 32, Issue 3).

Peter L. Lutz, John A. Musick, & Jeanette Wyneken. (2002). The Biology of Sea Turtles, Volume II. *The Biology of Sea Turtles, Volume II*. https://doi.org/10.1201/9781420040807

Portier, K., Moisson, P., Cupulatta, A., Shela Farhayldes Souza Domingues, F., Silva Araujo, M., BdO, H.-P., Ghdr, A., Silva Júnior, da L., & Lbm, P. (2022). *Case report: An innovative non-invasive technique to manage shell injuries in C. carbonarius*.

Rodríguez, C. E., Duque, A. M. H., Steinberg, J., & Woodburn, D. B. (2018). Chelonia. In *Pathology of Wildlife and Zoo Animals* (pp. 825–854). Elsevier. https://doi.org/10.1016/B978-0-12-805306-5.00034-1

Silverman, J. M. ,MD;, Mink Jerrohd H., M., & Deutsch Andrew L, M. (1989). *Discoid Menisci of the Knee: MR Imaging Appearance'*.

Simantiris, N. (2024). The impact of climate change on sea turtles: Current knowledge, scientometrics, and mitigation strategies. In *Science of the Total Environment* (Vol. 923). Elsevier B.V. https://doi.org/10.1016/j.scitotenv.2024.171354

Spotila, J. R. (2004). *Sea turtles : a complete guide to their biology, behavior, and conservation*. 227.

Wise, T. B., & Stayton, C. T. (2017). *Side-necked Versus Hidden-necked*. *73*(1), 18–29. https://doi.org/10.2307/26534349

Wyneken, J. (2004). La Anatomía de las Tortugas Marinas. *Fisheries Science*, 172.

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