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USE OF ADDITIVE MANUFACTURING IN VETERINARY MAXILLOFACIAL PROSTHETICS

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Abstract: The article is focused on orthodontic disorders and the use of additive production in solving problems in the maxillofacial area. Important information in veterinary orthodontics is the knowledge of the most common orthodontic disorders occurring in animals of various species and the consequences of not resolving these disorders. Dental health is no less important for both domestic and farm animals. With new approaches such as additive production, it is possible to achieve individualized aids that can be applied to any animal. The aim of the article is to draw attention to additive production and to point out its potential in the field of veterinary orthodontics. Examples of the use of additive production in this area can be found at the end of the work.

1 Introduction

Additive manufacturing is currently gaining prominence in many areas. Thanks to various successful applications, it has also found application in veterinary medicine and is gradually beginning to be used to solve various orthodontic disorders in animals. The potential of 3D printing in veterinary orthodontics lies mainly in its flexibility, adaptability and ability to print even small and detailed objects, which is very desirable and appreciated in the production of orthodontic appliances. Orthodontics in the veterinary field deals with the direction of the growth of animal teeth. In general, it could be said that animal orthodontics deals with a greater extent with cases where the treatment of teeth is necessary for the animal, especially from a health point of view, as opposed to the humane one, which is also interested in cosmetic treatment. The primary goal of animal orthodontics is to provide the animal with relief from pain caused by improper dental growth, bite disorders — i.e., small occlusion, improper tooth count, persistent deciduous teeth, blocked teeth, FRLs- Feline odontoclastic resorptive lesions, or diastema. It is estimated that of the dog population, only 7% are completely free of any dental problems. The teeth, together with the entire oral cavity, are the gateway to the body, and thus the health of this part is extremely important for the overall health of the individual. The target group is various animals, including dogs, cats and, for example, rabbits and other small animals.

The relative position of the upper and lower rows of teeth is called occlusion. It is basically a clash of upper and lower incisors with the mouth closed. Normal bite in a dog occurs when the six upper incisors are placed just in front of the six lower incisors (*Figure 1* A). The lower ocular tooth fits between the upper ocular tooth and the incisor so that there is no friction between them and they do not interfere (*Figure 1* B). The molar teeth fit together in the shape of a triangle (*Figure 1* C). Occlusion is largely genetically determined, but it is also affected by the animal's nutrition, the environment in which it lives and also mechanical damage. Sometimes, however, occlusion acquires various abnormalities, resulting in a wide range of dental disorders. Some abnormalities are also genetically determined, such as malocclusion, specifically pre-bite and under-bite, but many of them only occur during the life of the animal. In dogs, the frequent trigger is too strong and often stretched, for example, with a rope or towel, which causes the teeth to move to an unusual position. Complicated childbirth and the injuries that can occur also

affect the condition of the teeth, and even then, the first signs of abnormalities may appear. Malocclusion is one of the most common diseases in the field of animal orthodontics. It is a bite disorder that is caused by the incorrect position of the teeth and includes pre-bites or under-bites. A relatively common phenomenon is non-decayed deciduous teeth, missing teeth, or, conversely, an excessive number of teeth in the oral cavity [1].

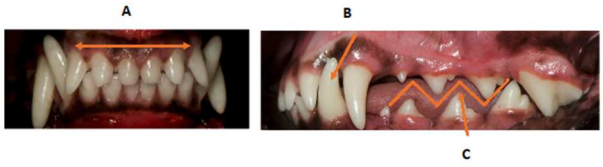

Figure 1 Normal bite in a dog

Because the oral cavity is never sterile, orthodontic procedures allow various bacteria to enter the air from the patient's mouth and wounds, so it is ideal to have a separate room reserved for such procedures.

During the treatment of the oral cavity and teeth, the patient is under general anaesthesia with endotracheal intubation. This prevents bacteria and other pollutants from being inhaled back from the air and also suffocates the animal. The pharyngeal wrap is also recommended but must be removed before extubation [2].

2 Basic orthodontic appliances

2.1 Coronal tooth amputation

It is accessed in the case of FRLs. In larger cases, it is no longer possible to save the tooth after the onset of the disease, and therefore amputation of the affected tooth is necessary to at least alleviate the pain. The entire extraction process is monitored at X-ray intervals at regular postoperative intervals to ensure that the tooth root is resorbed and that healing occurs without complications. The aim of this technique is to ensure that the tooth pulp remains undamaged and that the other teeth develop normally and contribute to the overall strength of the jaw [2][3].

2.2 Orthopaedic wire

Interdental or interfragmentary techniques, or combinations thereof, are used to repair certain jaw injuries, including fractures. With the help of wire sutures, tension wires, or intraosseous (intraosseous) screws, the primary fixation of large jaw fragments is ensured. Many veterinarians use a stabilizing technique of cerclage wire applied to the teeth of a dog. For cats, nylon suture is used instead of wire. Jaw damage is usually removed in 4 to 6 weeks. An X-ray is required to confirm the remedy, and then the wire is removed [2].

2.3 Tooth extraction

This technique is usually indicated for small animals. Extraction of the whole tooth is a relatively large intervention in the oral cavity of the animal, and an alternative may be endodontic therapy or reconstruction of the crown. The advantage of extracting the whole tooth is the elimination of any pathological changes on the left residue. The most common causes of this procedure are malocclusion, persistent deciduous teeth, or the excessive number of teeth **Chyba! Nenašiel sa žiaden zdroj odkazov.Chyba! Nenašiel sa žiaden zdroj odkazov.**.

2.4 Removable orthodontic appliance/aid

An underbite is a relatively common orthodontic problem in dogs. This malocclusion can be caused by a dental abnormality, a skull skeletal abnormality, or a combination of both. The tips of the eye teeth of the lower jaw cause unpleasant pain in the upper climate. If the problem is not solved, holes may even form in the climate, resulting in infections or ulcerations. A removable orthodontic appliance can be very helpful in this case, and correction of malocclusion can occur after only three to four weeks. However, if there are no signs of improvement after three weeks, another method must be used. The advantage is, among other things, that during the use of the device, the owner's relationship with the dog improves because the dog takes the device as a game. However, this technique is not suitable for all cases, especially not for puppies with deciduous teeth. This is because deciduous teeth are very brittle and prone to breakage. It is effective for adult dogs with long-lasting teeth, which, however, have no other orthodontic problems [2][4].

3 Materials and aids used in veterinary orthodontics

As the demand for veterinary dentists has been increasing more and more recently, the requirements for the quality of their work have also increased. The basic procedures practised by dentists include dental hygiene, surgical extraction of multi-root teeth, orthodontics and the like. For such operations, it is necessary to have adequate technical equipment, including various hand tools, dental ultrasonic scaler cleaners (scanners), polishers, or more professional high-performance dental units and X-ray systems [2].

3.1 Dental plates

There are many types and sizes of dental plates designed for use in dogs and cats. In the case of other animals, due to the different widths and lengths of the patient's mouth, the plates are made to measure individually [5].

3.2 Imprint

Toothache is an essential part of many dental procedures. It allows the doctor to determine the shape and condition of the oral cavity and to design a possible denture [5].

3.3 Tooth model

The tooth model should be made as soon as possible after the casting has been made. Thanks to the model, it is possible to evaluate oral structures, orthodontic bites, design a plan for treatment, or create orthodontic aids **Chyba! Nenašiel sa žiaden zdroj odkazov.**.

3.4 Fixed apparatus

It is used to apply forces to the teeth in order to achieve orthodontic movements. The fixed apparatus is not intended for all animals. In the beginning, it is necessary to consider the temperament of the animal, whether it will tolerate this orthodontic appliance, whether it has no signs of aggressive chewing of food, which could be a major complication, or whether extraction is simply not more appropriate [4].

3.5 Rings

In orthodontics, they are used to direct the tooth in the right direction of growth but also to fasten other acrylic and metal orthodontic appliances [5].

3.6 Brackets

Brackets are used to correct incorrectly turned teeth. On the prefabricated model, the lines according to which the breeches are placed are marked with a pencil [5].

3.7 Orthodontic wires

Annotations 188 wires are most commonly used in veterinary orthodontics, meaning that the wire consists of 18% chromium, 8% nickel, and the remainder is iron. Elgiloy wire, which also contains cobalt and molybdenum, is also relatively common [5].

4 Use of 3D printing in veterinary maxillofacial prosthetics

Although 3D technology has been used in human medicine since 1990, the first use in veterinary medicine did not appear until the early 21st century. The first registered cases concerned the treatment of complications in dogs with the incorrect forearm and thigh growth. The solutions consisted of the use of SLA technology of 3D printing for the production of preoperative models, which ultimately shortened the total time of the operation itself and reduced the risk of various complications. Since then, additive production has slowly spread to all branches of veterinary medicine, including orthodontics. However, it still does not use the full potential of 3D printing technology in dentistry, and so far, there are very few specific clinical studies that would offer additive manufacturing as a solution to orthodontic disorders. In a larger proportion, maxillofacial prosthetic devices are applied after injuries or cancer [6][7][8].

4.1 3D printed implant for labrador

A 15-month-old labrador lost a tooth after an injury while playing. This caused him complications in eating. The dog stopped eating and began to be apathetic. Since it was a loss of permanent teeth, it was necessary to look for a solution, because there was a threat that the dog would become malnourished. The first step was to create a casting of the upper jaw, and then the 3D design specialists created a model of the tooth, which will be made of metal, using chromium and cobalt (Figure 2 A). A scan of the same tooth from the other side of the mouth helped them to ensure complete adjustment of the implant. During the manufacture of the implant, it was necessary to pay attention to a thorough and accurate measurement so that the tooth fits perfectly, as it was a very small space (Figure 2 B). As a result, the extruded tooth was even harder than the original, but even so, in such cases, it is no longer recommended to let the dog bite hard objects, such as bones, to prevent possible implant fractures. The tooth took hold and the dog began to eat again after a short recovery (Figure 2 C) [9].

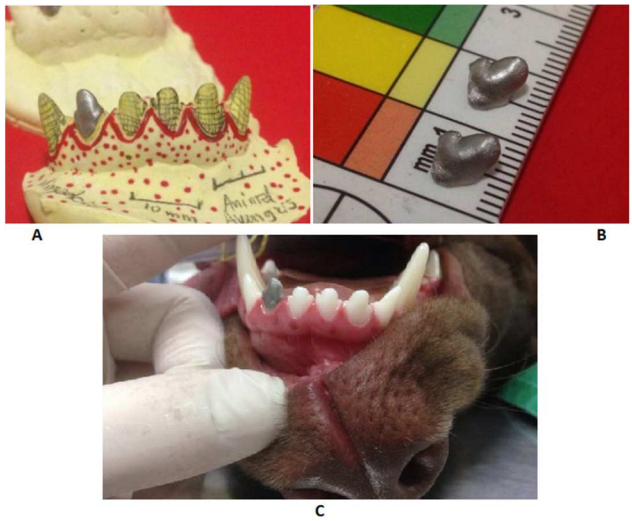

Figure 2 Jaw casting (A), thorough implant measurement (B), finished applied implant (C)

4.2 The helmet as an orthodontic aid for cockatiels

As some rhino prostheses made for birds, which only serve to correct the deformed beak, tend to loosen, in 2019, French veterinarian Minh Huynh managed to produce an alternative. It is a 3D printed helmet for a cockatiel, which is to serve as an orthodontic aid for beak correction (Figure 3). However, according to the author, its effects are still being investigated, and there is currently no more public information about it [8].

Figure 3 3D printed helmet for beak correction for cockatiel

4.3 Face mask for a turtle

A 30-year-old turtle suffered an injury under unknown circumstances, which caused a small wound to the right nostril. The wound began to fester, and there was a risk of the infection spreading. The veterinarians managed to clean the pus but was left with a deep wound in which food, clay and moss were constantly jammed. A year of intensive wound cleaning led veterinarians to look for a more permanent solution, which came in the form of a 3D printed mask that would prevent dirt from entering the wound. However, they faced a great challenge because the mask had to have the exact dimensions and shape so that the head of the turtle could fit into it and also that the mask did not restrict it in activities such as breathing or eating. The final mask was preceded by several test trials, which served as teaching aids. Based on detailed images of the turtle's face captured by a micro-scanner, technicians designed a mask that was large enough to fit a head but small enough to fit into armour and prevent the turtle from eating, seeing, and breathing. The mask was attached to the turtle with a screw that passes directly through the wound to the mouth, where it is fixed with composite resin. Figure 4 is a photograph of a turtle already with a face mask applied [10][11].

Figure 4 Turtle with the mask applied

4.4 Replica sledge for sea turtle

In June 2015, a 45-kilogram sea turtle got too close to a motorboat, whose propeller hit it several times. This caused extensive injuries to her upper and lower sledges. Injuries severely limited her food intake and ability to swim. Volunteers from the Turkish university PAU began looking for a solution to help it. In cooperation with the local 3D printing centre, they managed to make an exact replica of the missing part of the jaw. Based on a CT image of the turtle, they created a 3D model of the implant of the missing part of the jaw and its adjacent part using the software. Despite many experiences with human implants, this project was a relatively big challenge for the authors because the turtle has completely different anatomy and tissues than humans. Prior to finalization with the press itself, many motion analyzes were performed, as the strength of the turtle's jaws is very large. The implant was finally extruded from medical titanium, and several orthopaedic screws were used to attach it to the turtle. **Chyba! Nenašiel sa žiaden zdroj odkazov.** is a photograph of a turtle with an applied implant after surgery and 3D models of the upper and lower jaw implant **Chyba! Nenašiel sa žiaden zdroj odkazov.**.

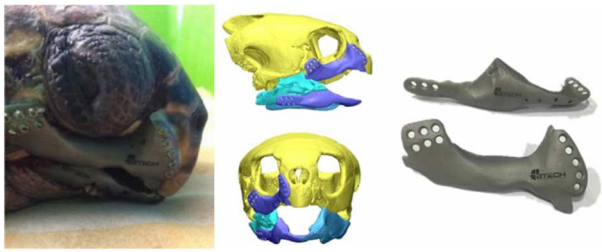

Figure 5 Turtle after implant application (left) and 3D models of the implant (right)

4.5 Maxillofacial mask for dog

In November 2017, an international group of surgeons from Germany, Canada and the United Kingdom teamed up to help the 7-year-old Bernese Mountain Dog with cancer through additive production. He had an operation during which he had to surgically remove a tumour in the left part of his upper jaw, which would cause him to lose a substantial amount of hard tissue. Due to the size and complexity of the affected area, surgeons opted for a customized 3D extruded titanium implant to replace the bone structure.

Whereas once individual printed devices were used only for a few patients with complicated cases, today, thanks to technological advances from individual printed devices, special medical CAD tools are becoming part of standard veterinary and human practice. Using DICOM (digital tool for imaging and communication in medicine), a 3D model of the affected part of the dog's head was generated on the basis of CT / MRI images. Using the model, an implant design was created, which was then repeatedly compared and measured according to 3D scans and head models before printing so that it fits as well as possible, see Figure 6. As a result, the placement of the implant was much simpler, more predictable and faster, which made it possible to shorten the time during which

the dog had to be under general anaesthesia. The process of designing and printing the device itself lasted a total of two weeks, which was an advantage because the tumour was constantly growing, and if the manufacturing process stretched for a long time, the extruded implant would no longer have to fit. During an operation led by Canadian veterinary surgeon Julius Liptak, his entire tumour was removed, including adjacent infested areas measuring 45 millimetres x 50 millimetres and 30 millimetres thick. The photograph from the course of the operation is shown in Figure 7. They then applied an implant in place, which they fastened with surgical screws. A prepared skin flap was used to cover the affected area and the implant. This ensured that the structure of the nose did not have to be modified due to the missing tissue, thanks to which the dog did not feel any extraordinary physiological changes after the operation. The day after the operation, the dog could go back to home care, and after a few days, he was able to breathe normally and eat himself. X-rays of the implant applied to the dog's jaw are shown in Figure 8. An individual 3D printed maxillofacial mask will provide him with a long and full life without restrictions, which, however, would not be possible without 3D printing technology, as the tumour-affected part of the face was very large [13].

Figure 6 The 3D model of the implant itself (left) and preparation for surgery using a 3D model of the head (right)

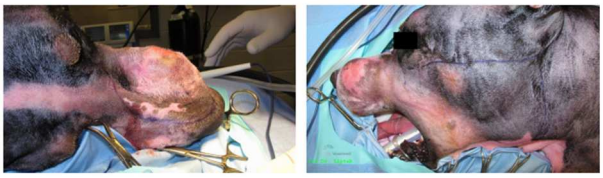

Figure 7 The course of the operation

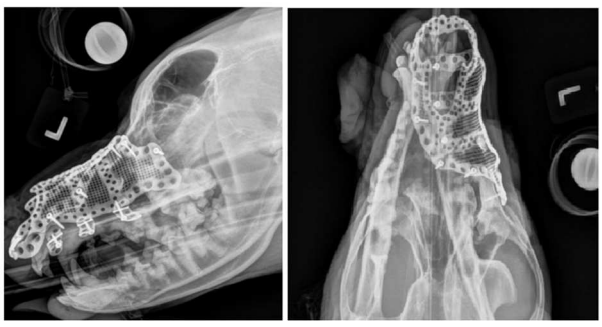

Figure 8 X-ray after surgery: side (left) and bottom view (right)

5 Conclusions

The article deals with orthodontic disorders in various animals, aids that are used to solve these disorders and the use of 3D printing in this area. The aim was to summarize the knowledge of the issue and process it into an overview theoretical work aimed at raising the potential of additive production in veterinary orthodontics.

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