Scientific Works. Series C. Veterinary Medicine. Vol. LXXI (2), 2025
ISSN 2065-1295; ISSN 2343-9394 (CD-ROM); ISSN 2067-3663 (Online); ISSN-L 2065-1295

PLANNING ORBITAL AND FACIAL BONE IMPLANTOLOGY IN CATS USING CT VOLUMETRIC RECONSTRUCTIONS AND CAD TECHNOLOGIES: CASE REPORT AND FINANCIAL CHALLENGES

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Abstract

Advanced imaging and 3D reconstruction technologies are transforming veterinary surgical planning by enabling precise and customized interventions. This case report describes a 14-year-old cat with a facial mass, where CT imaging revealed extensive bone lysis affecting the orbit and adjacent facial bones. Volumetric CT data were used to create a 3D model of the skull, which served as the basis for designing a custom titanium implant via CAD and 3D printing. While these implants provided a potential solution for restoring anatomical integrity, the owner ultimately declined surgery due to financial constraints. This report highlights the potential of integrating CT imaging, 3D reconstructions, and CAD technologies in veterinary implantology, while emphasizing the financial and logistical challenges that limit the accessibility of these advanced solutions.

Key words*: 3D printing, bone lysis, CAD technologies, CT volumetric reconstructions, orbital reconstruction, veterinary implantology.*

INTRODUCTION

Veterinary implantology has advanced significantly in recent decades, driven by progress in imaging technologies and additive manufacturing (3D printing). Computed tomography (CT) - based volumetric reconstructions, when combined with computer-aided design and manufacturing (CAD/CAM) workflows, have enabled the creation of patient-specific implants with unprecedented anatomical precision. These innovations are transforming veterinary surgery by offering highly customized solutions for complex craniofacial reconstructions in companion animals.

Facial and orbital bone tumours in cats, although relatively rare, are often highly aggressive. Malignancies such as fibrosarcomas, osteosarcomas, and undifferentiated sarcomas are characterized by local invasiveness, extensive bone destruction, and a poor response to conventional therapies (Dobromylskyj, 2022; Harvey et al., 2022). Due to their infiltrative behaviour and anatomical location, accurate preoperative assessment is critical. Conventional radiography is insufficient for evaluating the extent of these tumours, whereas CT-based volumetric imaging provides a comprehensive three-dimensional view of bone involvement (Villamizar-Martinez, 2022).

The integration of CAD/CAM and 3D printing into veterinary surgery was initially explored for maxillofacial and orbital reconstruction in canine patients, with encouraging results (Park et al., 2020). More recent reports have demonstrated its applicability in feline cases as well. These technologies enable the design and fabrication of highly customized implants that provide superior anatomical and biomechanical fit, thereby reducing the risk of postoperative complications. Recent findings further support this approach, showing that 3D-printed implants based on generative design can biomechanically outperform conventional and manually designed systems in veterinary mandibular reconstruction (Baumgartner et al., 2023). Furthermore, preoperative virtual planning and anatomical modelling enhance surgical precision and reduce intraoperative time (Hobert et al., 2024; Thatcher & Soukup, 2022).

Despite their potential, the high cost of customized implants remains a limiting factor in veterinary practice. While a patient-specific craniofacial implant for a cat may range from €1,000 to €1,200, equivalent procedures in human medicine often exceed €10,000. Although this cost difference highlights the relative affordability of veterinary solutions, such expenses still represent a financial burden for many pet owners, especially in the absence of insurance coverage.

In this case report, we describe a 14-year-old male European domestic shorthair cat diagnosed with a highly invasive craniofacial tumour. Using CT imaging and CAD/CAM techniques, a custom titanium implant was designed to restore the extensive bony defect. However, due to financial constraints and the patient's advanced age, the surgical intervention was ultimately declined. This case illustrates both the technical feasibility of advanced implantology in feline patients and the economic and ethical challenges that can limit its clinical implementation.

MATERIALS AND METHODS

This case study focuses on a 14-year-old male European domestic shorthair cat that was presented to the University Veterinary Emergency Hospital "Prof. Dr. Alin Bîrțoiu" due to a progressively enlarging swelling in the left craniofacial region. Physical examination revealed a mass that deformed the left orbital and nasal areas, displacing the globe and demonstrating infiltrative characteristics. Given the clinical suspicion of a neoplastic process, a thorough diagnostic protocol was initiated, which included advanced imaging techniques and cytological evaluation.

The mass caused significant facial asymmetry and deformation of the left orbit and maxillary region (Figure 1).

The patient was anesthetized using an inhalation protocol, followed by a computed tomography (CT) examination of both the skull and thorax using a Philips Access 16-slice CT scanner. The scanning protocol included helical acquisition sequences, performed pre- and post-contrast, with image reconstructions optimized for soft tissue, pulmonary parenchyma, and osseous structures.

Figure 1. Clinical appearance of the cranial mass. (a) Lateral view highlighting soft tissue expansion and orbital displacement; (b) Frontal view demonstrating marked facial distortion and medial deviation of the left eye

The CT analysis revealed an extensive, highly aggressive mass involving the left side of the face (Figure 2). Notably, there was significant bone lysis affecting multiple bones of the viscerocranium (a detailed description of CT findings is provided in the Results section).

The extent and pattern of craniofacial bone destruction raised a strong suspicion of a high-grade undifferentiated sarcoma, warranting immediate cytological evaluation to support diagnostic confirmation and guide treatment planning.

Figure 2. Multiplanar CT reconstructions in bone window settings illustrating the extent of the craniofacial mass and associated osteolysis:

(a) Transverse plane showing asymmetry of the orbits and severe lysis of the left orbital wall and adjacent structures; (b) Dorsal plane demonstrating expansive bone destruction involving the maxilla, nasal cavity, and frontal bone; (c) Parasagittal plane highlighting infiltration of the mass into the rostral and frontal cranial bones with distortion of normal skull contours

Immediately following the imaging, and while the patient remained under general anaesthesia, a fine-needle aspiration biopsy (FNAB) was performed. Cytological examination revealed a poorly differentiated malignant mesenchymal tumour, highly suggestive of feline fibrosarcoma with associated neutrophilic inflammation (Figure 3). The imaging and cytopathology findings supported the decision to attempt a radical surgical resection followed by reconstructive implant placement.

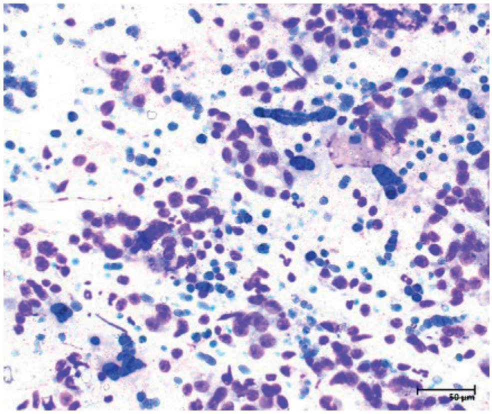

Figure 3. Fine needle aspiration - mesenchymal cells with anisocytosis, anisokaryosis, and a spindle-like appearance (May-Grünwald Giemsa stain, 400×)

After confirming the diagnosis, attention was turned to reconstructive planning. High-resolution computed tomography (CT) scan data of the feline skull were exported in Digital Imaging and Communications in Medicine (DICOM) format. The dataset was processed using InVesalius (Campinas, Brazil), a medical image segmentation software that enables precise differentiation of osseous structures based on Hounsfield Unit (HU) values.

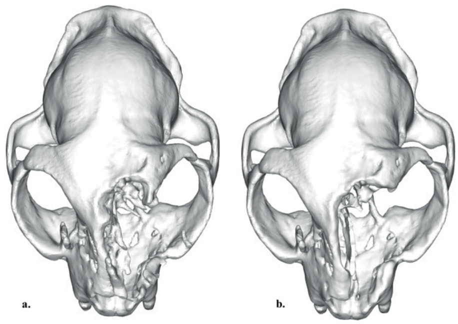

Figure 4. 3D skull model preparation:
(a) initial skull reconstruction showing fragments;
(b) model after virtual removal of loose fragments and smoothing of defect margins

The segmentation process isolated the bone tissue from soft tissue and artifacts, ensuring a high-fidelity reconstruction of the anatomical structures. A three-dimensional (3D) volumetric model of the skull was generated using a threshold-based algorithm, which accurately captured the bone morphology and provided a foundation for subsequent virtual reconstruction and implant design. This step was critical for ensuring an optimal anatomical fit of the custom implant and facilitating preoperative planning (Kapoor, 2024).

The reconstructed 3D skull model was further processed using Geomagic Freeform (Oqton, San Francisco, USA), an advanced haptic-based freeform modelling software that enables high-precision digital sculpting. Initially, loose bone fragments were removed, and the fracture margins were virtually smoothed to create a stable foundation for implant design (Figure 4).

Next, screw trajectories were strategically planned, optimizing their positioning to ensure secure fixation and even load distribution. The implant's overall shape was designed based on a mirrored reconstruction of the contralateral side, ensuring anatomical symmetry and optimal fit (Figure 5).

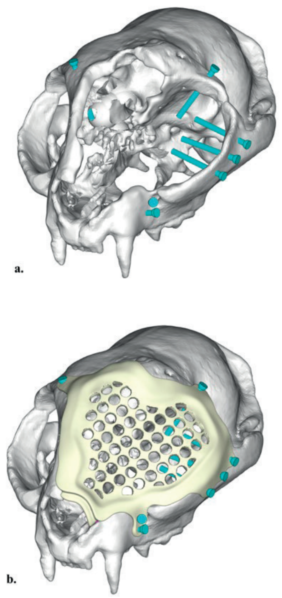

Figure 5. (a) Planned screw trajectories shown on the skull model; (b) Initial implant shape based on the mirrored contralateral anatomy

To enhance both functionality and biological integration, weight-reducing mesh holes were incorporated into the plate, facilitating soft tissue attachment and vascularization. Additionally, the inner edge of the implant was engineered with a porous structure, designed to promote osseointegration and bone ingrowth, improving long-term stability (Figure 6).

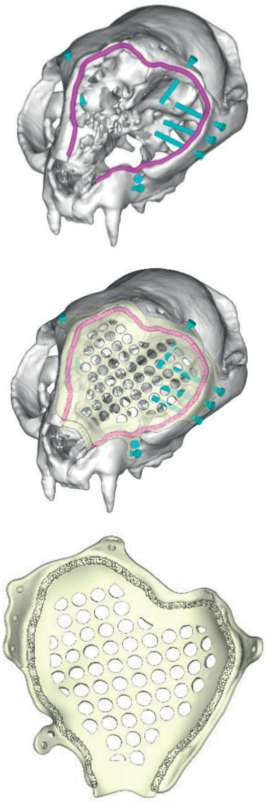

Figure 6. Porous inner margin of the implant designed to promote osseointegration and bone ingrowth

This step ensured that the implant maintained optimal biomechanical compatibility while preserving natural anatomical contours. The design incorporated locking screw trajectories optimized for mechanical stability and load distribution, minimizing stress concentrations and reducing the risk of postoperative complications.

The finalized implant design underwent pre-processing for additive manufacturing using Materialise Magics (Materialise NV, Leuven, Belgium), a software suite dedicated to error correction, mesh refinement, and topology optimization for 3D printing. The implant was produced using Selective Laser Melting (SLM), an advanced powder bed fusion (PBF) technology, employing Ti6Al4V titanium alloy, which was selected for its superior biocompatibility, corrosion resistance, and mechanical strength.

Following additive manufacturing, the implant underwent post-processing procedures to ensure optimal precision, mechanical integrity, and biocompatibility:

Mechanical grinding and polishing to refine surface roughness and remove residual manufacturing irregularities (Figure 7).

Precision CNC machining of locking screw holes to achieve high accuracy in fixation placement.

Electropolishing to enhance the surface finish, reduce bacterial adhesion, and improve osseointegration properties (Figure 8).

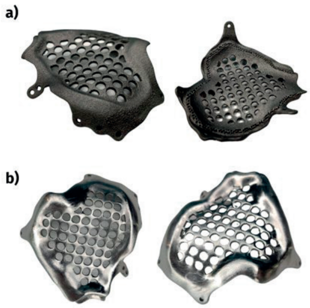

Figure 7. Implant post-processing: (a) raw implant after 3D printing and removal of support structures; (b) implant after mechanical grinding and polishing

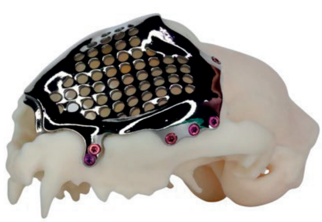

Figure 8. Implant after drilling of locking screw holes and final electropolishing, mounted on the 3D-printed skull model for fit verification.

The implant was sterilized via autoclaving before surgical implantation to ensure compliance with standard surgical asepsis protocols (Klasen et al., 2022).

To optimize surgical navigation and preoperative planning, a full-scale anatomical skull model was fabricated using high-resolution 3D printing. Two versions of the model were created:

(1) preoperative model representing the skull in its original state, allowing for comparative analysis and strategic planning.

(2) modified model with the planned tissue resection, providing enhanced visualization of the surgical site and enabling precise intraoperative anatomical navigation.

Additionally, a custom CNC-machined drill guide was designed and manufactured to fit the locking screw trajectories of the implant. The guide was engineered to ensure accurate drilling of screw insertion points, thereby improving surgical precision and fixation stability. This comprehensive approach enabled the surgeon to pre-measure and select appropriate screw lengths before surgery, minimizing intraoperative adjustments and enhancing procedural efficiency.

Although the custom implant was successfully engineered, the surgery was ultimately not performed due to financial constraints and the patient’s advanced age.

RESULTS AND DISCUSSIONS

The patient presented with a rapidly progressive, firm, and infiltrative mass in the left craniofacial region, significantly distorting the normal anatomical structures. The displacement of the left eye and the involvement of adjacent bony structures raised concerns about an aggressive neoplastic process. Computed tomography (CT) imaging provided a comprehensive assessment, revealing extensive bone lysis affecting multiple craniofacial structures, including the nasal bones, lacrimal bone, frontal bone, maxilla, vomer, and orbital wall. The lesion extended into the frontal sinuses and possibly compressed the left frontal lobe of the brain (as shown in Figure 2). The thoracic CT scan identified a small mineralized lesion within the right cranial lung lobe, which, although not definitively metastatic, contributed to the overall poor prognosis of the patient (White et al., 2020).

Cytological evaluation of fine-needle aspirates confirmed the presence of a poorly differentiated mesenchymal tumour, with characteristics highly suggestive of feline fibrosarcoma. This malignancy is known for its locally invasive nature, rapid progression, and poor response to conventional treatment modalities (Dobromylskyj, 2022; Harvey et al., 2022). Given the extent of osseous destruction and the compromised structural integrity of the skull, radical surgical resection followed by

reconstructive implantation was considered the most viable resolution strategy.
Following the segmentation of CT data, the creation of a 3D volumetric model enabled an in-depth evaluation of the anatomical defect. This model served as the foundation for designing a custom titanium implant, tailored to replace the lost bone structures and restore biomechanical function. Using mirrored contralateral geometry as a reference, the implant was designed with a porous structure at its inner edges to enhance osseointegration, while strategically placed perforations facilitated soft tissue attachment and vascularization.
A key aspect of the design process was optimizing screw trajectories to ensure secure fixation while minimizing stress concentrations. Prior studies have highlighted the importance of precise screw positioning in preventing implant instability and post-surgical complications (Thatcher & Soukup, 2022). In this case, the locking screw trajectories were meticulously planned to achieve a stable fixation with minimal interference to surrounding structures.
While the preoperative planning and implant fabrication processes were successfully executed, the surgical intervention was not performed due to financial constraints. The estimated total cost of the engineering and manufacturing process ranged from €1,000 to €1,200, which poses a significant expense for many pet owners. Although this cost is substantially lower than comparable procedures in human medicine - where patient-specific craniofacial implants often exceed €10,000 - the financial burden remains a critical limiting factor for the feasibility of such advanced interventions in veterinary practice.
In veterinary surgery, financial considerations often dictate treatment choices, and in many cases, highly sophisticated procedures remain inaccessible to the majority of pet owners. This economic disparity is further exacerbated by the lack of widespread insurance coverage for advanced veterinary interventions, unlike in human healthcare systems. As previously reported, cost-effective alternatives such as polycaprolactone-based bioresorbable scaffolds have been explored for certain maxillofacial reconstructions in small animals, but they remain experimental and do not offer the same level of biomechanical stability as titanium-based implants (Kang et al., 2022).
Another significant challenge was the patient's advanced age of 14 years, which added complexity to the overall prognosis. Elderly feline patients undergoing major reconstructive surgeries are at increased risk of prolonged recovery, impaired bone healing, and systemic complications. Given the locally aggressive and infiltrative nature of the tumour, long-term survival post-surgery remained uncertain, further influencing the owner’s decision to decline the procedure.
Despite the cancellation of the surgical procedure, this case underscores the transformative role of 3D printing and CAD technologies in veterinary reconstructive surgery. The ability to design and manufacture patient-specific implants with high precision represents a significant advancement in veterinary orthopaedics and maxillofacial surgery. The digital workflow - including preoperative virtual surgical planning, 3D model fabrication, and implant prototyping - has been successfully implemented in several recent studies focused on cranial reconstruction in veterinary patients (Hobert et al., 2024).
Furthermore, rapid advancements in biomaterials and additive manufacturing may soon lower costs, making these interventions more accessible. Recent research has explored bioprinting techniques, using calcium phosphate-based scaffolds that mimic natural bone properties, thereby improving the long-term biocompatibility of implants while reducing material costs (Castel et al., 2024).
A potential solution to cost-related challenges could be collaborations between veterinary and human medical research facilities, where excess resources and technology from human healthcare innovations could be adapted for veterinary applications. Additionally, the implementation of standardized protocols for implant manufacturing and multi-use templates for common anatomical reconstructions could further optimize production efficiency and affordability.
A critical component in veterinary reconstructive surgery is the ethical dilemma surrounding complex and high-cost procedures. Unlike human medicine, where the decision to undergo surgery is primarily dictated by medical

necessity, in veterinary practice, financial limitations and quality-of-life considerations weigh heavily in treatment planning. While the potential for full anatomical restoration existed in this case, the lack of long-term survival guarantees made the owner's decision to decline surgery a rational and compassionate choice.

Furthermore, quality of life in geriatric feline patients is an essential factor in determining the appropriateness of aggressive surgical interventions. Prolonged recovery periods, the risk of post-surgical infections, and the potential for tumour recurrence all contribute to decision-making complexities. Studies have suggested that in advanced cases where surgical excision is unlikely to achieve clean margins or where prognosis remains guarded, palliative approaches - such as radiation therapy or chemotherapy - may be preferable to radical surgery. This is particularly true in geriatric patients, where treatment decisions must also consider overall quality of life and comorbidities (Hendrick, 2016).

Although the surgical procedure was not executed, this case exemplifies the technological feasibility and precision of 3D-printed, patient-specific implants in veterinary medicine. The comprehensive engineering process - encompassing CT-based segmentation, virtual reconstruction, additive manufacturing, and preoperative modelling - demonstrated a remarkable degree of customization and biomechanical optimization. This approach offers a viable alternative to conventional maxillofacial reconstruction techniques.

Nevertheless, economic, ethical, and clinical considerations pose significant challenges to the widespread implementation of these interventions. Future research should prioritize strategies for cost reduction, innovation in biomaterials, and improved accessibility, ensuring that these promising technologies transition from experimental luxuries to viable treatment options for veterinary patients.

CONCLUSIONS

This case report demonstrates the growing potential of advanced imaging, virtual surgical planning, and additive manufacturing technologies in addressing complex craniofacial defects in veterinary patients. The integration of CT-based volumetric reconstructions, CAD modelling, and 3D printing offers unprecedented precision in the design and fabrication of patient-specific implants. In this case, the engineering process successfully produced a custom titanium prosthesis tailored to restore the extensive bony defects caused by an aggressive orbital and facial sarcoma in a geriatric feline patient.

The digital workflow - from anatomical segmentation and mirrored reconstruction to implant design, manufacturing, and surgical simulation - proved to be both technically feasible and clinically valuable. The design incorporated modern features such as weight-reducing perforations and porous interfaces to promote osseointegration, showcasing the biomechanical and biological sophistication now achievable in veterinary implantology.

However, this case also underscores a critical barrier in the application of these technologies: cost and accessibility. Although the estimated expense of €1,000-€1,200 for this level of engineering may appear modest compared to similar procedures in human medicine - often exceeding €10,000 - the cost remains prohibitive for many pet owners. This economic challenge highlights the need for further innovation not only in surgical techniques but also in the logistics, production efficiency, and financial models that govern their use in everyday veterinary practice.

Beyond financial constraints, ethical considerations - particularly in geriatric patients - play a crucial role in treatment planning. In this case, the owner was presented with an estimated cost of approximately €1,100 for the custom implant alone. When this financial burden was weighed alongside the patient's advanced age and uncertain prognosis, the owner ultimately decided against pursuing surgical intervention. Such decisions reflect the complex reality of veterinary medicine, where the feasibility of advanced care must often be balanced against emotional, ethical, and economic factors.

Continued evolution of 3D printing, biomaterials, and open-source digital tools may help to reduce costs and increase access to personalized surgical solutions in companion animals. Interdisciplinary collaboration, increased clinical experience, and greater awareness of these technologies are essential to

transforming them from pioneering case reports into standard-of-care options in veterinary practice.
Ultimately, this case not only illustrates the cutting-edge possibilities of veterinary reconstructive surgery, it serves as a reminder of the real-world limitations that must be addressed to bring these solutions to a broader population of animal patients.

ACKNOWLEDGEMENTS

The authors would like to express their sincere gratitude to the University of Agronomic Sciences and Veterinary Medicine of Bucharest, Faculty of Veterinary Medicine, for their support and access to clinical and imaging resources that made this case study possible.

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