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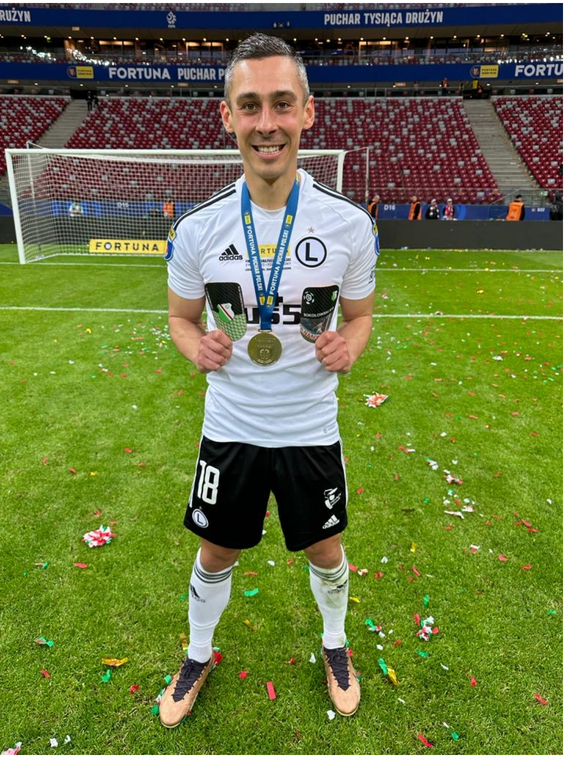

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Metal	3D Printing & CNC*	CNC (consider: 3D Printing)	CNC (consider: Investment Casting)	Investment or Die Casting

* : highly dependent on part geometry

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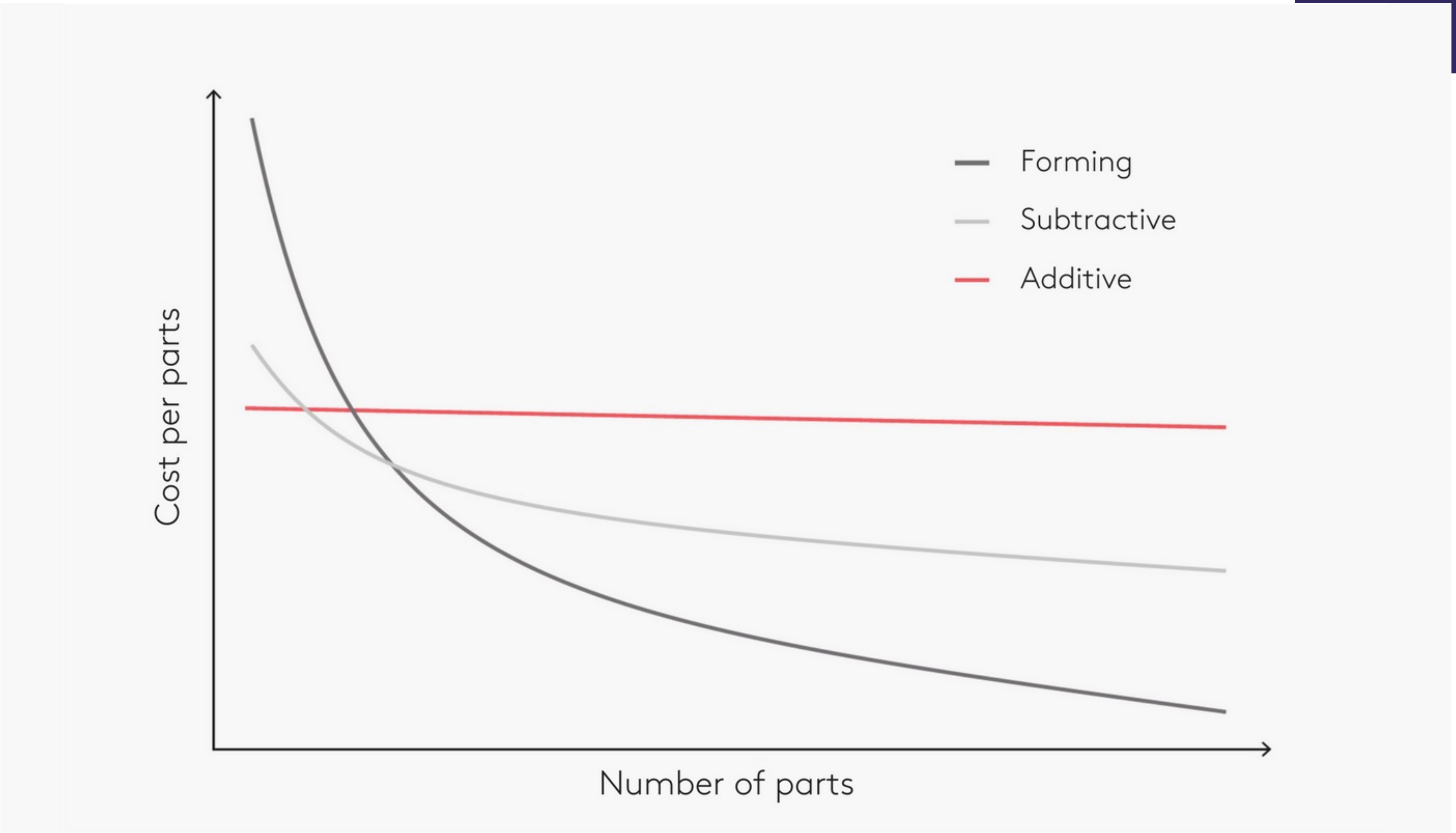

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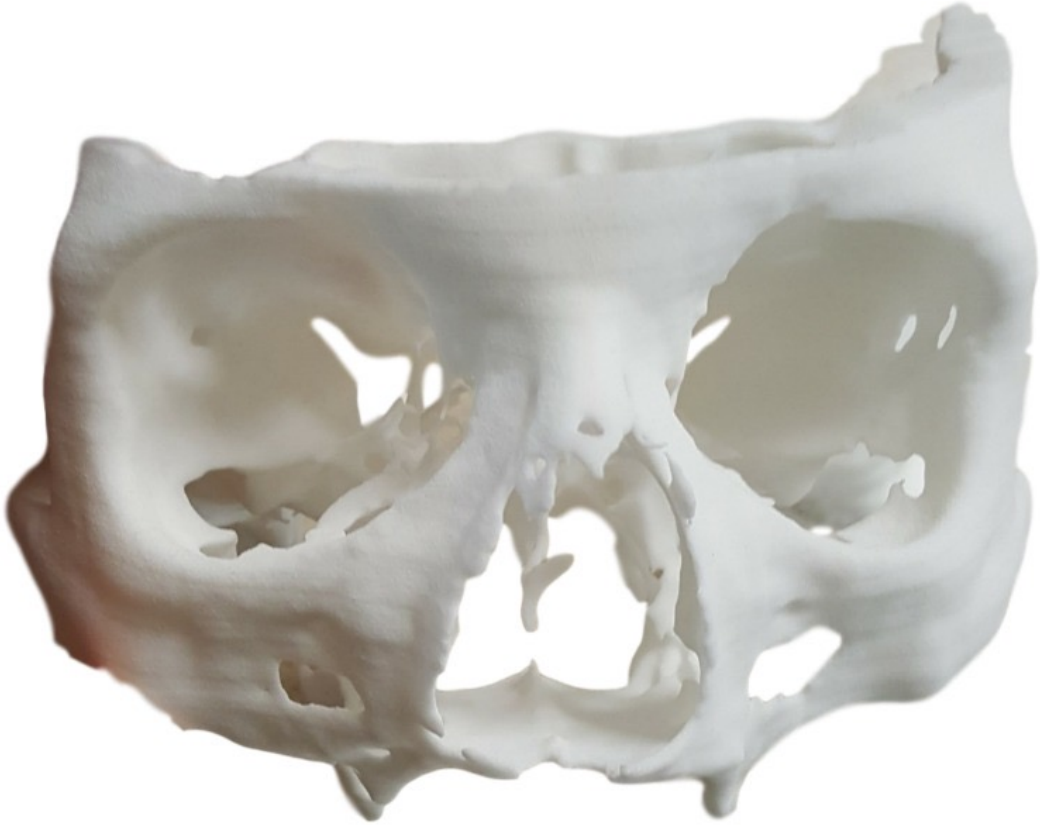

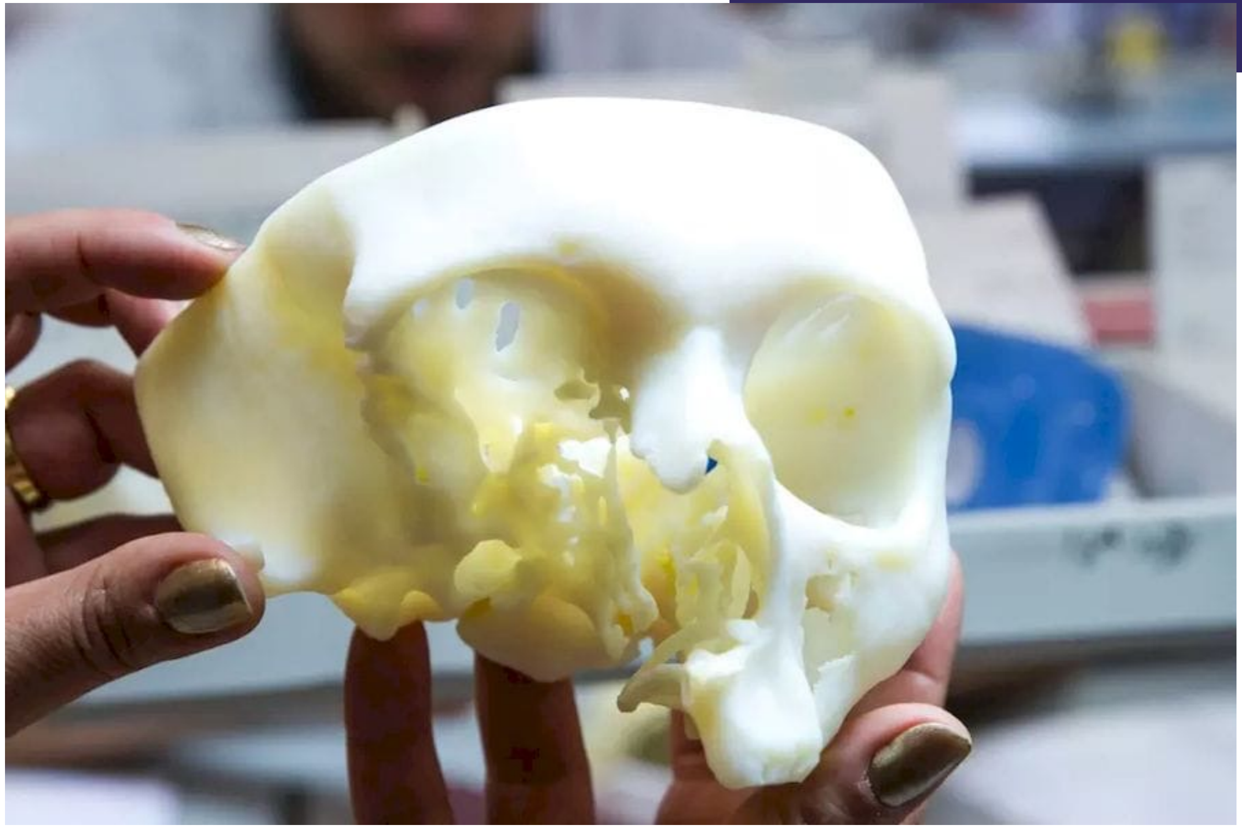

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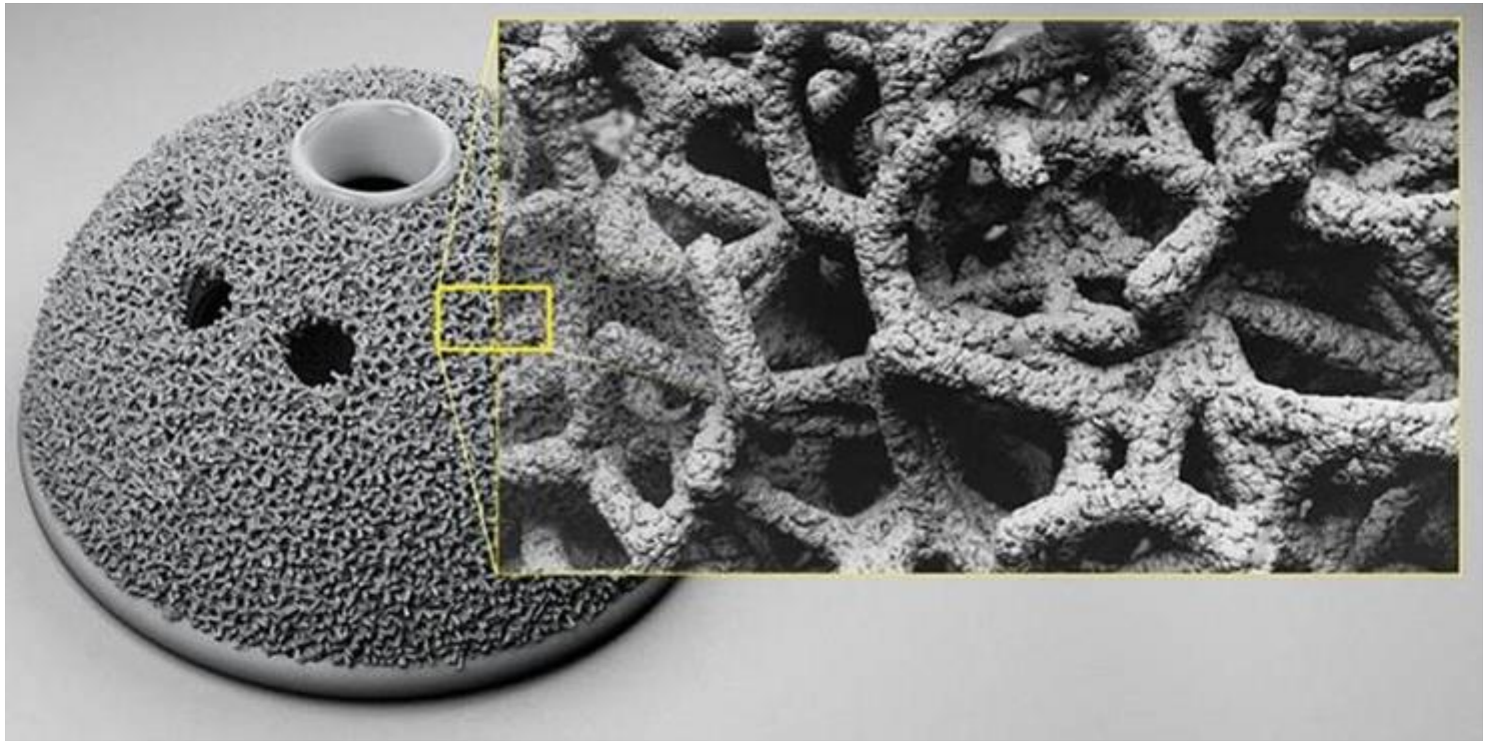

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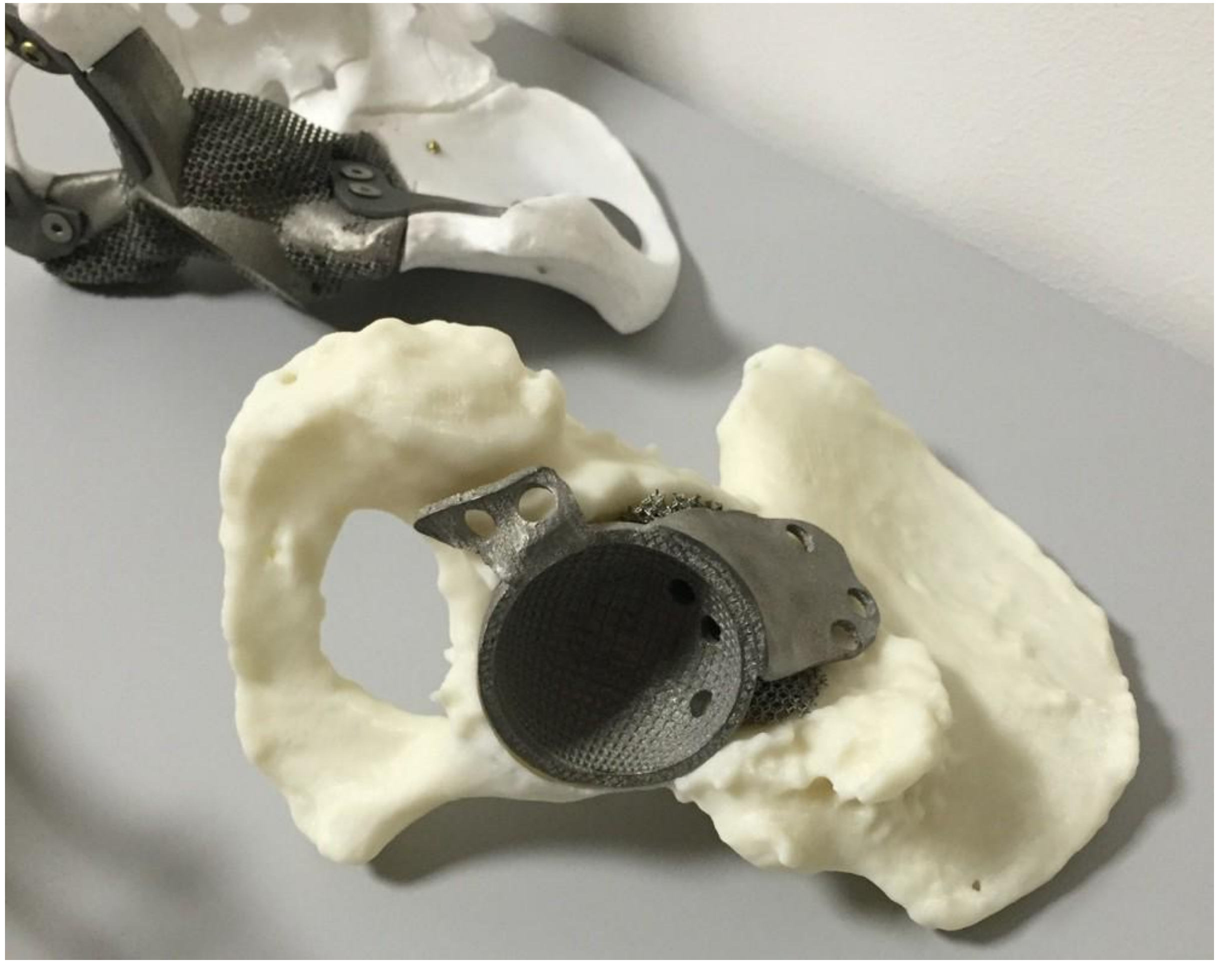

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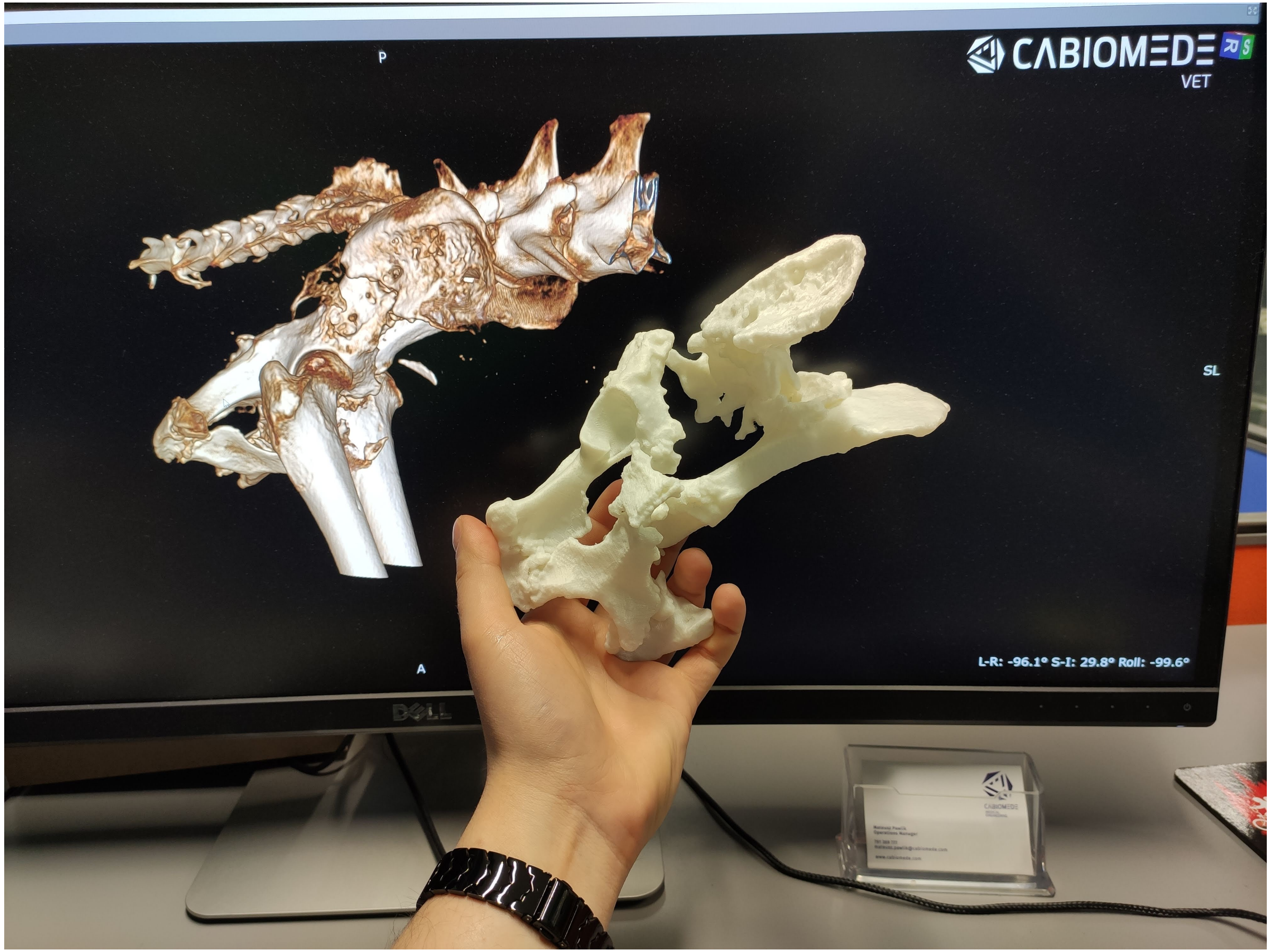

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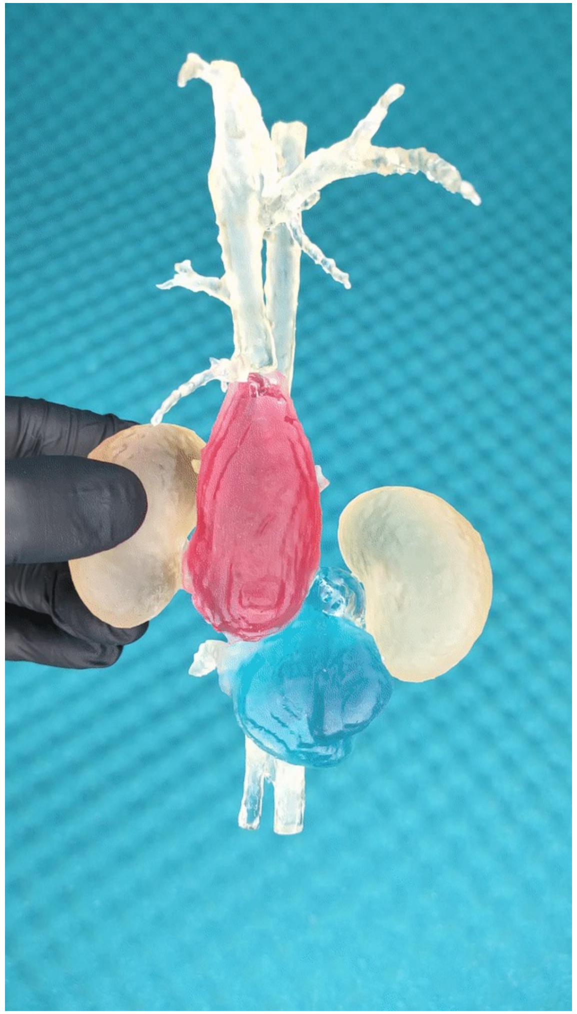

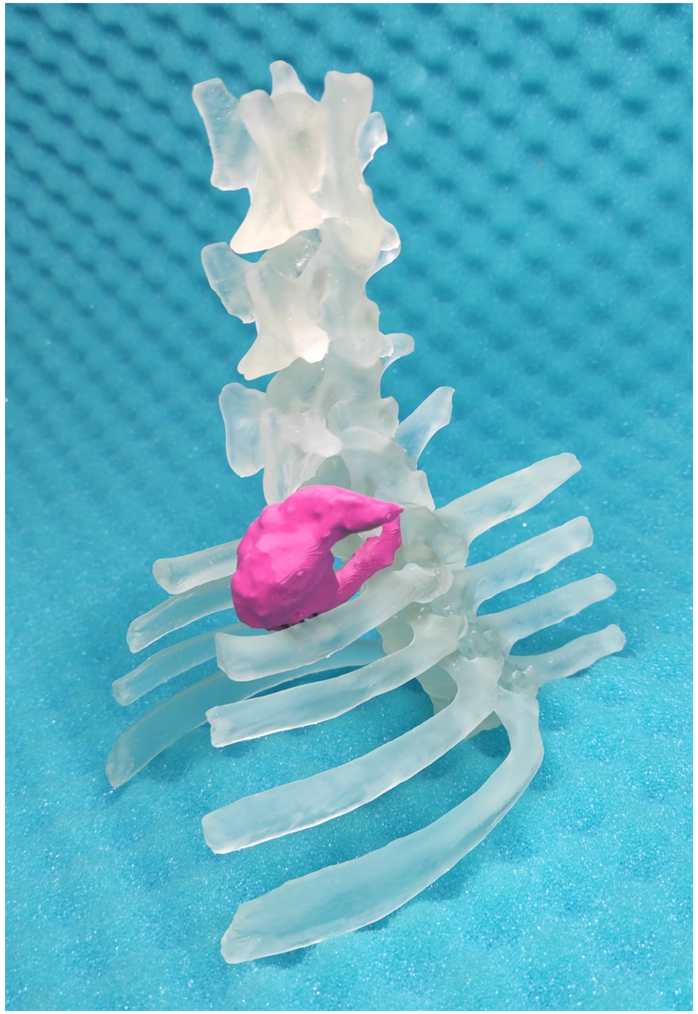

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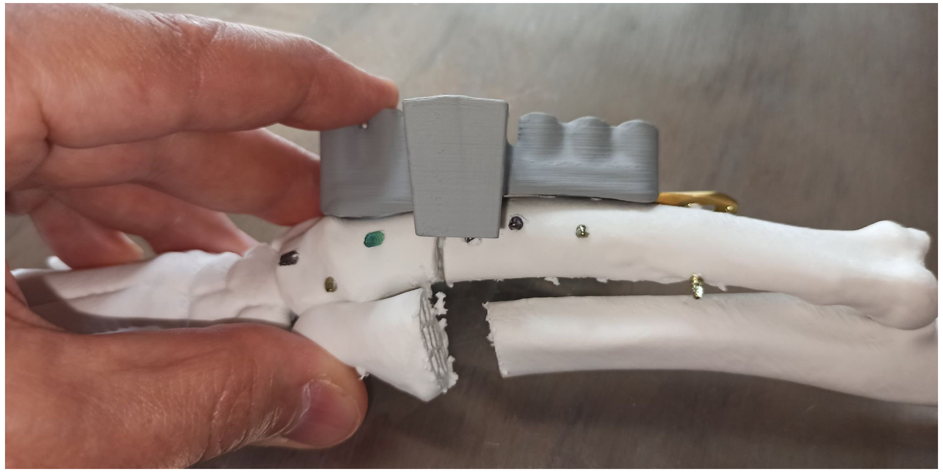

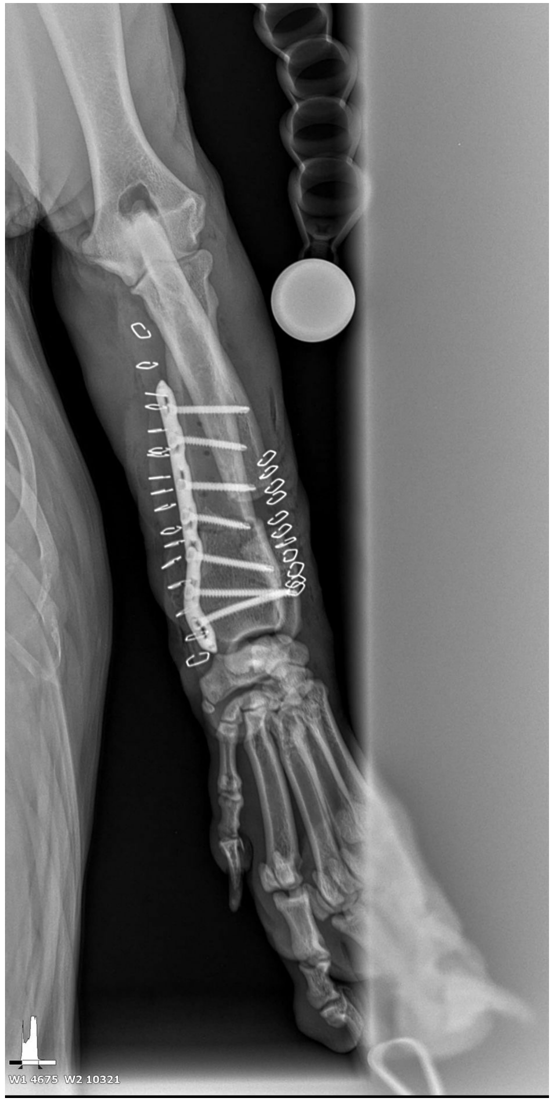

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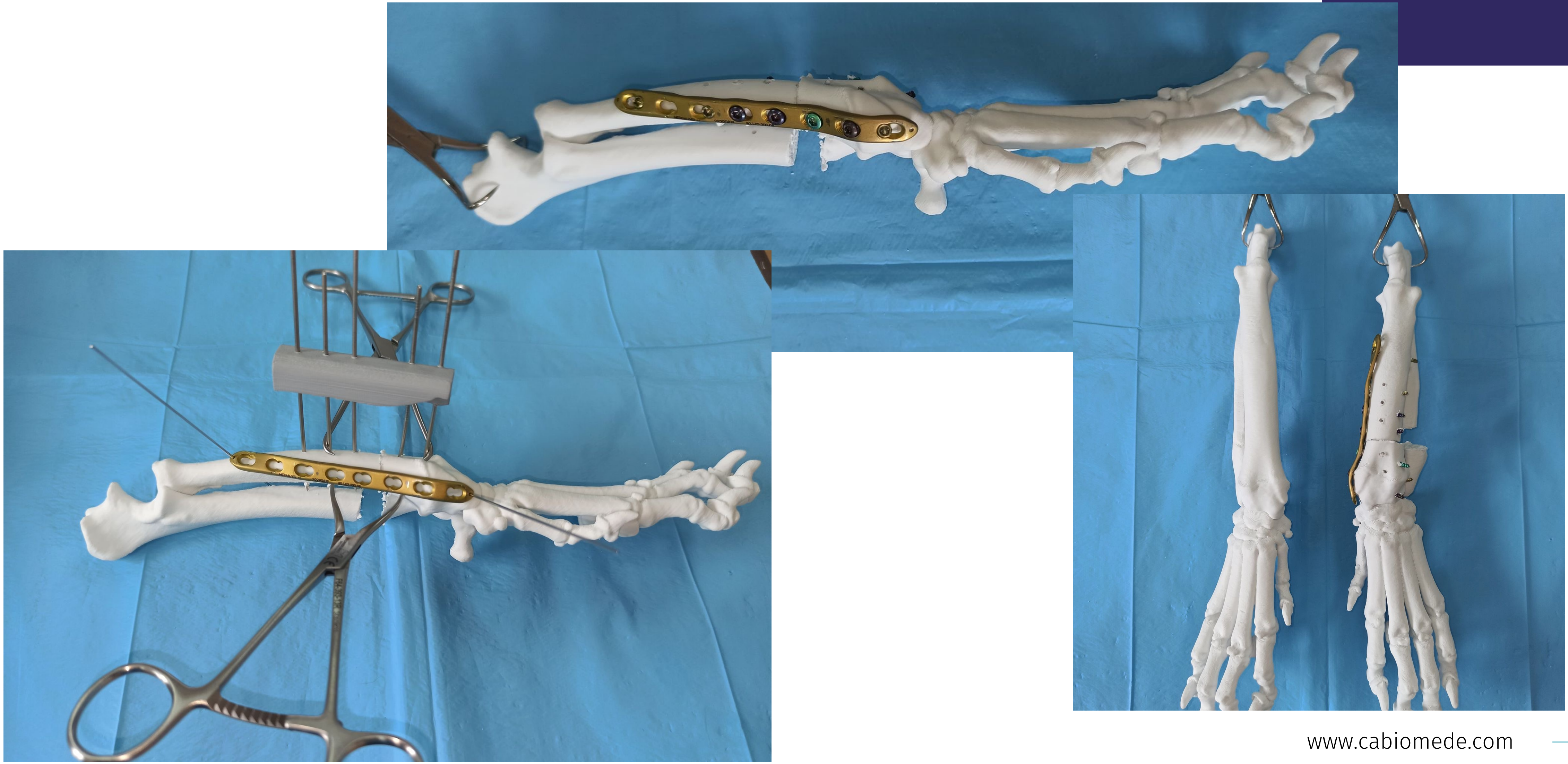

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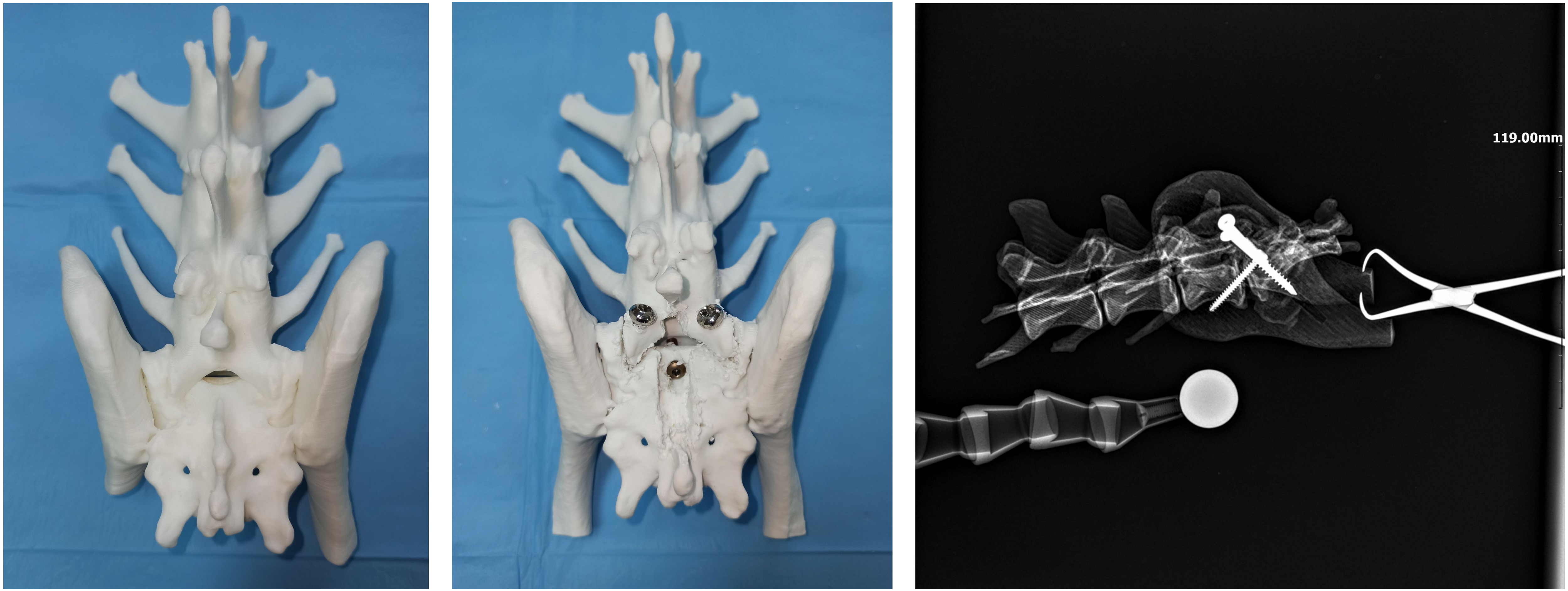

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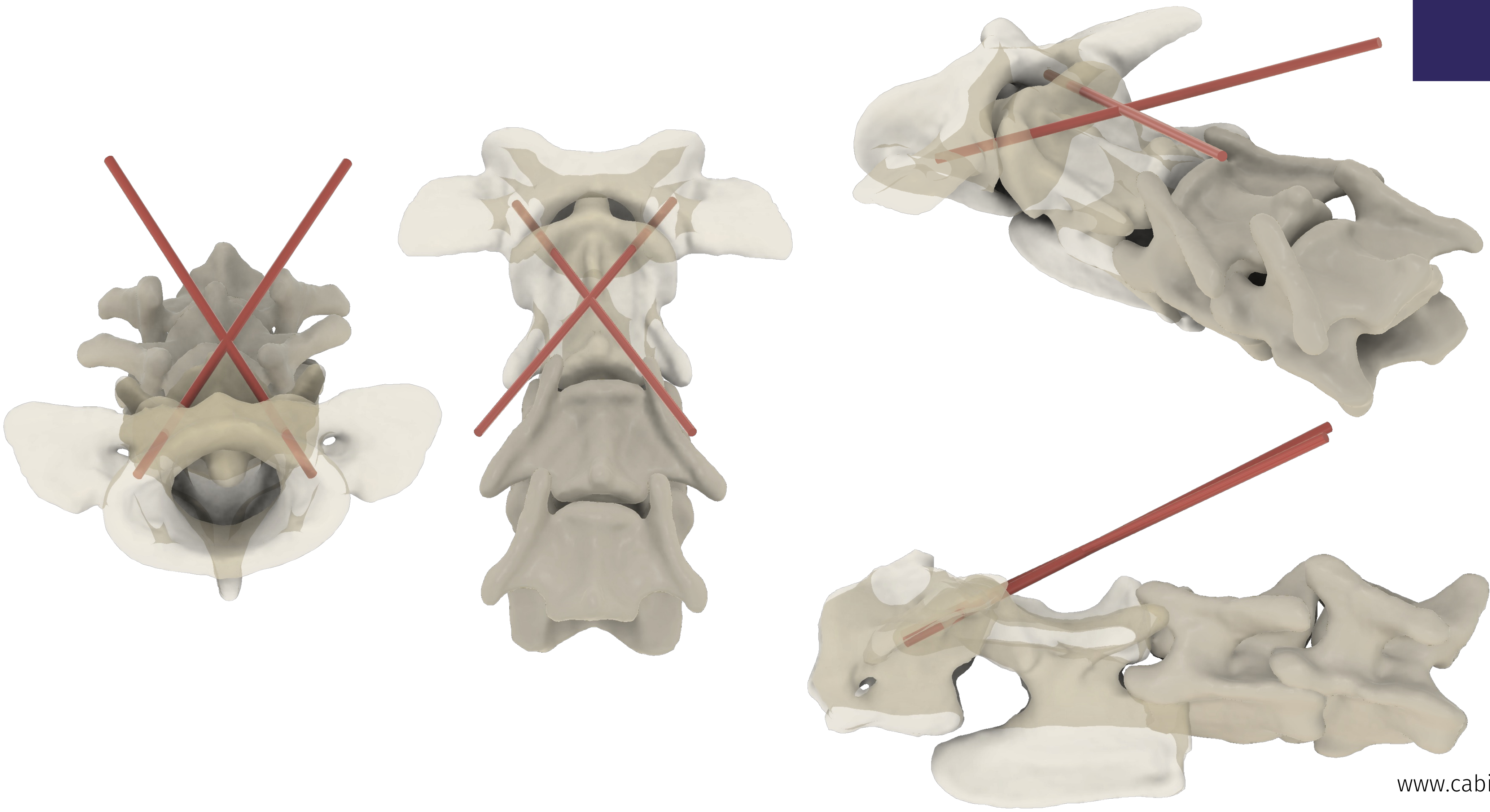

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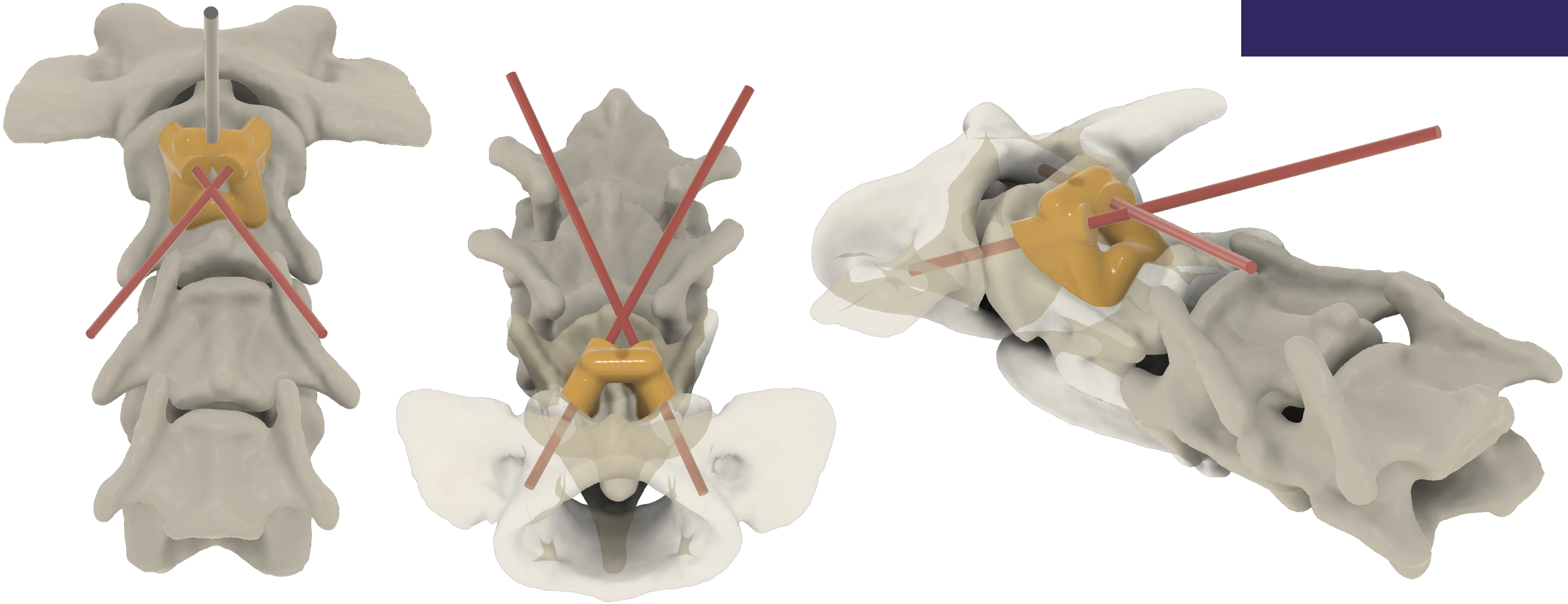

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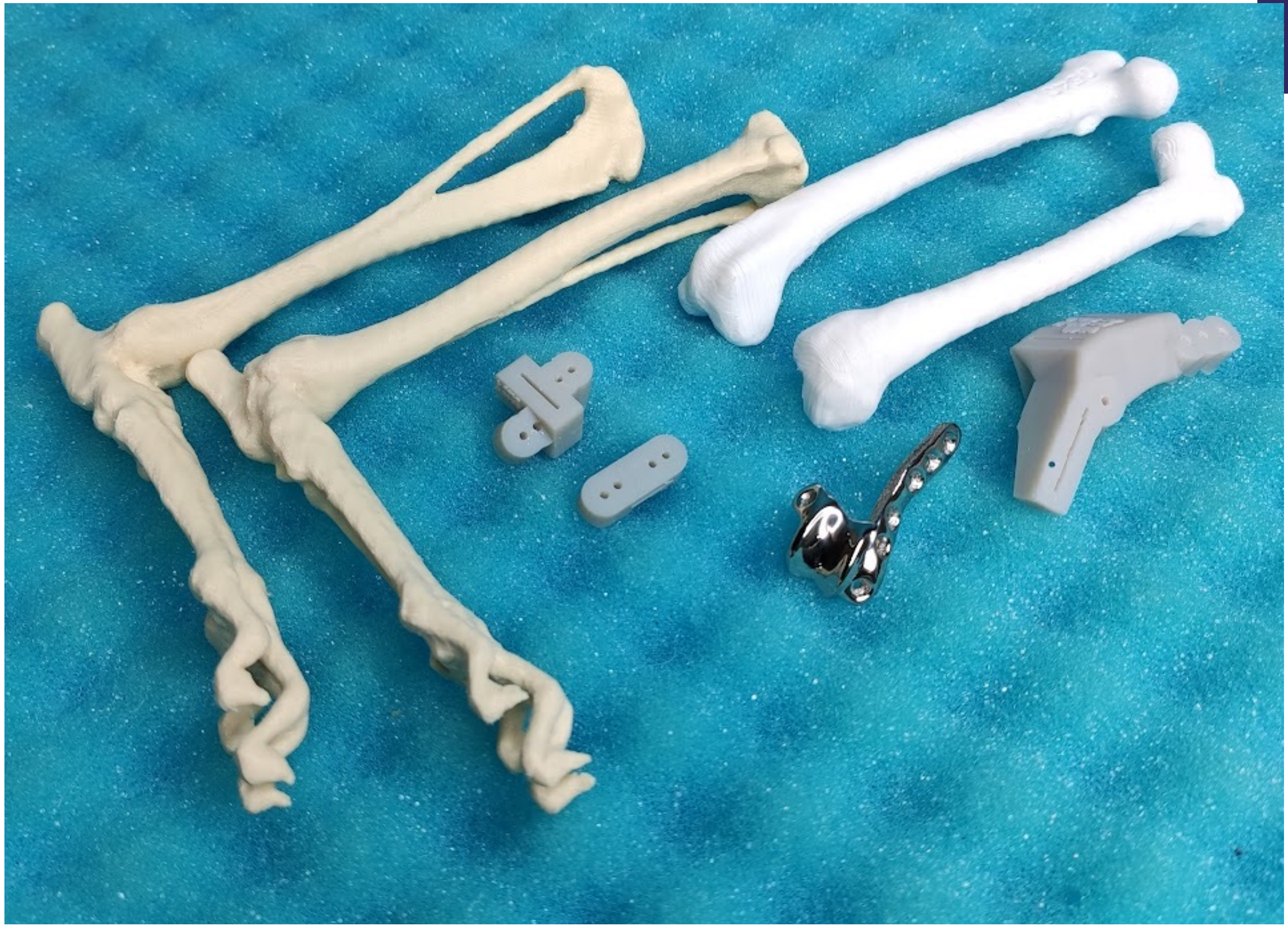

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Colored Bone Map - 3D printed bone models representing safety zones for orthopedic training and surgery planning

Piotr Trębacz, DVM, PhD.[1], Aleksandra Kurkowska, MEng.[2],
Anna Barteczko, MEng.[2], Mateusz Pawlik, MEng.[2]

[1]ChirWet, Gliwice, Poland
[2]CABIOMEDE Ltd., Kielce, Poland

2D 'flat data' vs 3D 'volumetric data'

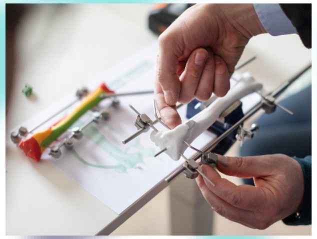
Two dimensional data obtained from X-ray or found in scientific articles or books require the surgeon to develop a mental three-dimensional image of the anatomy.
3D printed models can simplify this mental exercise and provide realistic and user-friendly portrayal of radiographic data but also be a handy tool in learning process, as well as reminder used during preparation for the surgery. Properly manufactured models suitable for disinfection or sterilization may be even used during the surgery, placed next to the patient in a role of anatomy map.

From greyscale CT data to multicolor print

On a basis of CT scan of healthy dog and cat, three-dimensional models of long bones and pelvises were developed with usage of medical segmentation software. Next, models were virtually colored representing safety zones intended to be used in external fixation surgery planning (long bones) or plates osteosynthesis (pelvises).
Dog long bones colored regions were devised on a basis of J.M. Marti and A. Miller articles - *Delimitation of safe corridors for the insertion of external fixator pins in the dog 1: Hindlimb & 2: Forelimb.*

Cat long bones colored regions and both dog and cat pelvises safety zones were developed on a basis of P. Trębacz knowledge and clinical experience.
Virtual models were then printed using commercial multicolor 3D printer modified by CABIOMEDE Ltd. specifically for this purpose.

Above work allowed to create physical colored models in 1:1 scale, suitable for disinfection and usage in medical application – both for learning and training, as well as surgery planning.
Further development of manufacturing method allows to create models suitable for steam sterilization in 121°C intended to be used during the surgery as an anatomy map representing safety regions of specific bone.



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ESVOT
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Semi elastic pelvis - MPO/DPO training development

Piotr Trębacz, DVM, PhD.[1], Aleksandra Kurkowska, MEng.[2]
Mateusz Pawlik, MEng.[1]

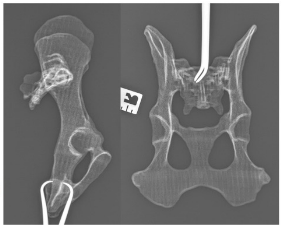
[1]ChirWet, Gliwice, Poland
[2]CABIOMEDE Ltd., Kielce, Poland

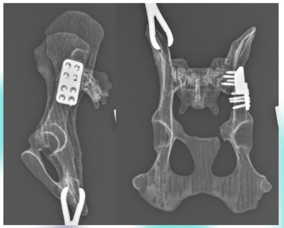
Cadaveric training vs Simulation

Cadaveric dissection passed the test of time with its educational value widely accepted by experienced surgeons. Nonetheless, it may be difficult to prepare a set of specimens of the same size, age, sex and race, with the same pathology to provide training for a group of surgeons. Development of 3D printing and biomaterials technologies could potentially provide alternative tools for surgical training. Proper preparation of data and physical model manufacturing encompass all the benefits of cadavers in terms of realism and clinical relevance without any of its ethical, infection, safety, and financial concerns.

MPO - DPO training

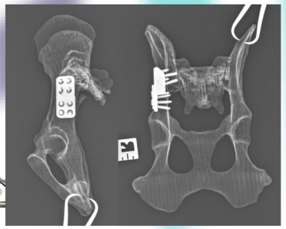
Mono Pelvic Osteotomy (MPO) or Double Pelvic Osteotomy (DPO) is performed on puppies with femoral head subluxation due to increased dorsal acetabular rim slope and/or excessive joint laxity. The purpose of MPO/DPO is the arrest the development of Hip Dysplasia in the early stage of the disease.
MPO/DPO modifies the direction of the forces inside the joint, redirecting the femoral head inside the acetabulum. Pelvis geometry and width are not affected and dedicated implants increase the stability of the construct.
The problem with MPO/DPO surgical training is the availability of puppies' cadavers which are important for proper procedure simulation due to a need of ischium and pelvic symphysis flexibility. Moreover, simulator should allow to assess procedure outcomes in X-ray imaging, mimicking the images surgeon would obtain on living patient.

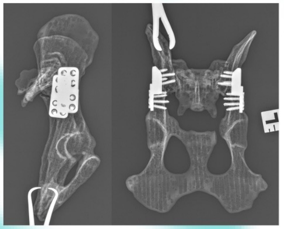




Semi-elastic model of dog pelvis, visible in X-ray imaging

On a basis of CT scan, pelvis model was segmented and postprocessed to get virtual representation of healthy dog anatomy. Internal structure mimicking cancellous bone and solid shell representing cortical bone was developed to provide density gradient across the model. Highly flexible Nylon with X-ray visibility modifiers was used to manufacture physical artificial bone using 3D printing technology. Further annealing below glass transition temperature of polymeric material allowed to obtain semi-elastic model mimicking natural bone. Proper annealing and manufacturing process settings were found crucial to provide not only desired rigidity of the model, but also machining properties – drilling and cutting with surgical instruments without excessive material melting. Surgeons should drill and cut model in similar way to natural bone.
A series of cuts was performed to verify usability of artificial bone in surgical training – both for MPO and DPO, as well as double sided osteotomy – combined MPO and DPO (plates and screws manufactured by Mikromed, Poland). Further series of X-rays confirmed good visibility of external shape and internal structures needed for surgical training outcomes assessment.





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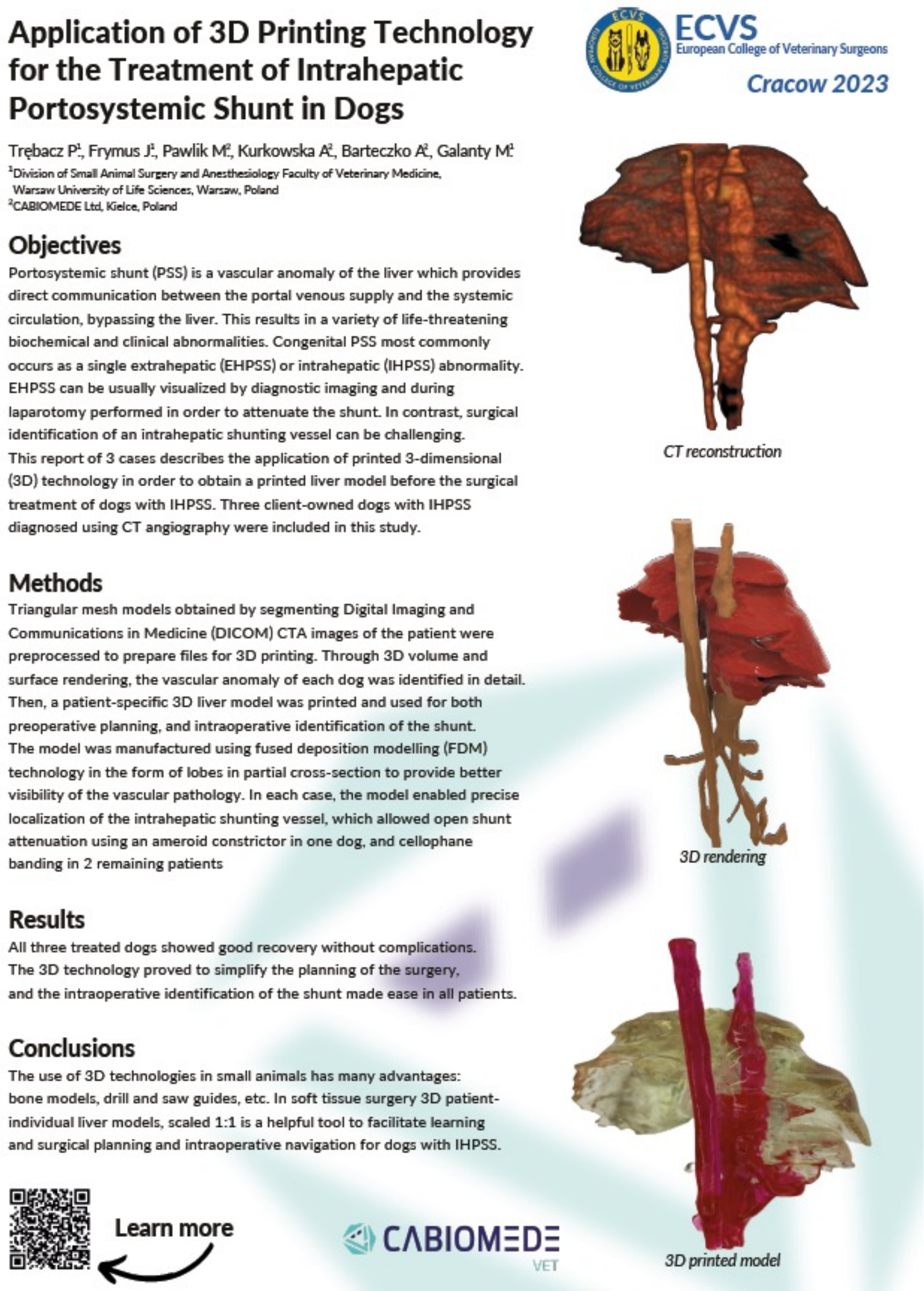

Application of 3D Printing Technology for the Treatment of Intrahepatic Portosystemic Shunt in Dogs

ECVS
European College of Veterinary Surgeons
Cracow 2023

Trębacz P.[1], Frymus J.[1], Pawlik M.[2], Kurkowska A.[2], Barteczko A.[2], Galanty M.[1]
[1]Division of Small Animal Surgery and Anesthesiology Faculty of Veterinary Medicine,
Warsaw University of Life Sciences, Warsaw, Poland
[2]CABIOMEDE Ltd, Kielce, Poland

Objectives

Portosystemic shunt (PSS) is a vascular anomaly of the liver which provides direct communication between the portal venous supply and the systemic circulation, bypassing the liver. This results in a variety of life-threatening biochemical and clinical abnormalities. Congenital PSS most commonly occurs as a single extrahepatic (EHPSS) or intrahepatic (IHPSS) abnormality. EHPSS can be usually visualized by diagnostic imaging and during laparotomy performed in order to attenuate the shunt. In contrast, surgical identification of an intrahepatic shunting vessel can be challenging.
This report of 3 cases describes the application of printed 3-dimensional (3D) technology in order to obtain a printed liver model before the surgical treatment of dogs with IHPSS. Three client-owned dogs with IHPSS diagnosed using CT angiography were included in this study.

CT reconstruction

Methods

Triangular mesh models obtained by segmenting Digital Imaging and Communications in Medicine (DICOM) CTA images of the patient were preprocessed to prepare files for 3D printing. Through 3D volume and surface rendering, the vascular anomaly of each dog was identified in detail. Then, a patient-specific 3D liver model was printed and used for both preoperative planning, and intraoperative identification of the shunt.
The model was manufactured using fused deposition modelling (FDM) technology in the form of lobes in partial cross-section to provide better visibility of the vascular pathology. In each case, the model enabled precise localization of the intrahepatic shunting vessel, which allowed open shunt attenuation using an ameroid constrictor in one dog, and cellophane banding in 2 remaining patients

3D rendering

Results

All three treated dogs showed good recovery without complications.
The 3D technology proved to simplify the planning of the surgery,
and the intraoperative identification of the shunt made ease in all patients.

Conclusions

The use of 3D technologies in small animals has many advantages:
bone models, drill and saw guides, etc. In soft tissue surgery 3D patient-individual liver models, scaled 1:1 is a helpful tool to facilitate learning
and surgical planning and intraoperative navigation for dogs with IHPSS.

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3D printed model

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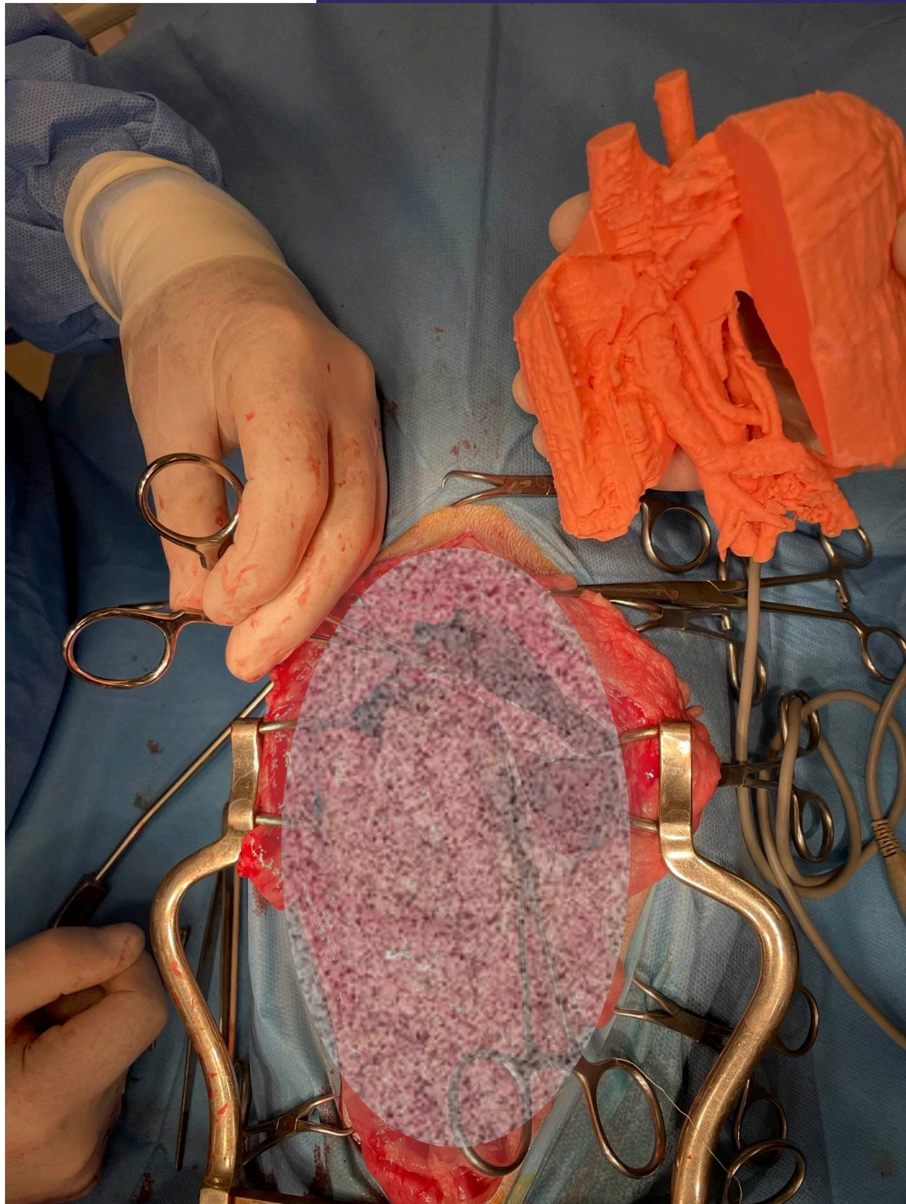

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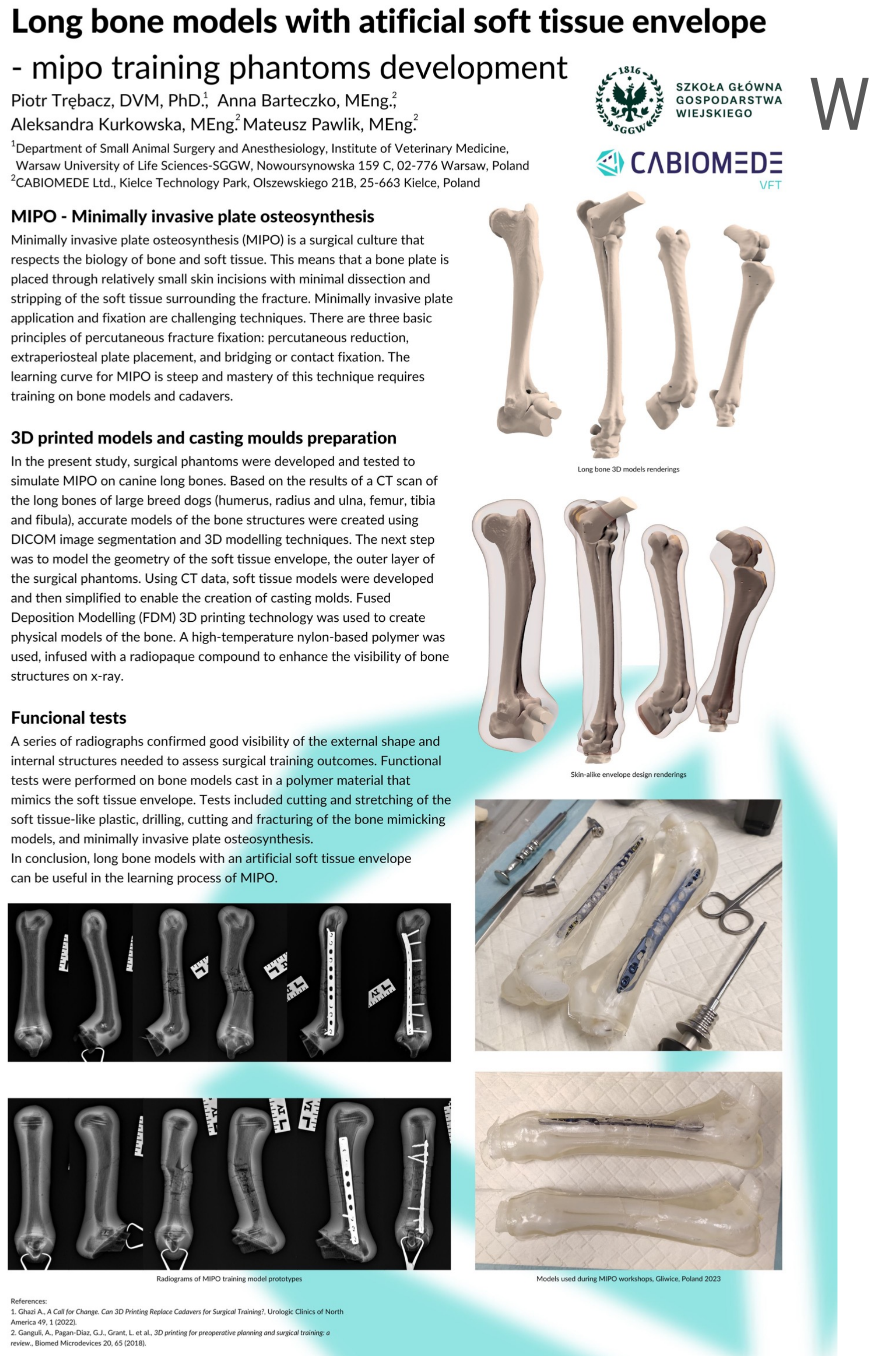

Long bone models with atificial soft tissue envelope - mipo training phantoms development

Piotr Trębacz, DVM, PhD.[1], Anna Barteczko, MEng.[2],
Aleksandra Kurkowska, MEng.[2] Mateusz Pawlik, MEng.[2]

[1]Department of Small Animal Surgery and Anesthesiology, Institute of Veterinary Medicine, Warsaw University of Life Sciences-SGGW, Nowoursynowska 159 C, 02-776 Warsaw, Poland
[2]CABIOMEDE Ltd., Kielce Technology Park, Olszewskiego 21B, 25-663 Kielce, Poland

MIPO - Minimally invasive plate osteosynthesis

Minimally invasive plate osteosynthesis (MIPO) is a surgical culture that respects the biology of bone and soft tissue. This means that a bone plate is placed through relatively small skin incisions with minimal dissection and stripping of the soft tissue surrounding the fracture. Minimally invasive plate application and fixation are challenging techniques. There are three basic principles of percutaneous fracture fixation: percutaneous reduction, extraperiosteal plate placement, and bridging or contact fixation. The learning curve for MIPO is steep and mastery of this technique requires training on bone models and cadavers.

Long bone 3D models renderings

3D printed models and casting moulds preparation

In the present study, surgical phantoms were developed and tested to simulate MIPO on canine long bones. Based on the results of a CT scan of the long bones of large breed dogs (humerus, radius and ulna, femur, tibia and fibula), accurate models of the bone structures were created using DICOM image segmentation and 3D modelling techniques. The next step was to model the geometry of the soft tissue envelope, the outer layer of the surgical phantoms. Using CT data, soft tissue models were developed and then simplified to enable the creation of casting molds. Fused Deposition Modelling (FDM) 3D printing technology was used to create physical models of the bone. A high-temperature nylon-based polymer was used, infused with a radiopaque compound to enhance the visibility of bone structures on x-ray.

Skin-alike envelope design renderings

Funcional tests

A series of radiographs confirmed good visibility of the external shape and internal structures needed to assess surgical training outcomes. Functional tests were performed on bone models cast in a polymer material that mimics the soft tissue envelope. Tests included cutting and stretching of the soft tissue-like plastic, drilling, cutting and fracturing of the bone mimicking models, and minimally invasive plate osteosynthesis.
In conclusion, long bone models with an artificial soft tissue envelope can be useful in the learning process of MIPO.

Radiograms of MIPO training model prototypes

Models used during MIPO workshops, Gliwice, Poland 2023

References:
1. Ghazi A., *A Call for Change. Can 3D Printing Replace Cadavers for Surgical Training?*, Urologic Clinics of North America 49, 1 (2022).
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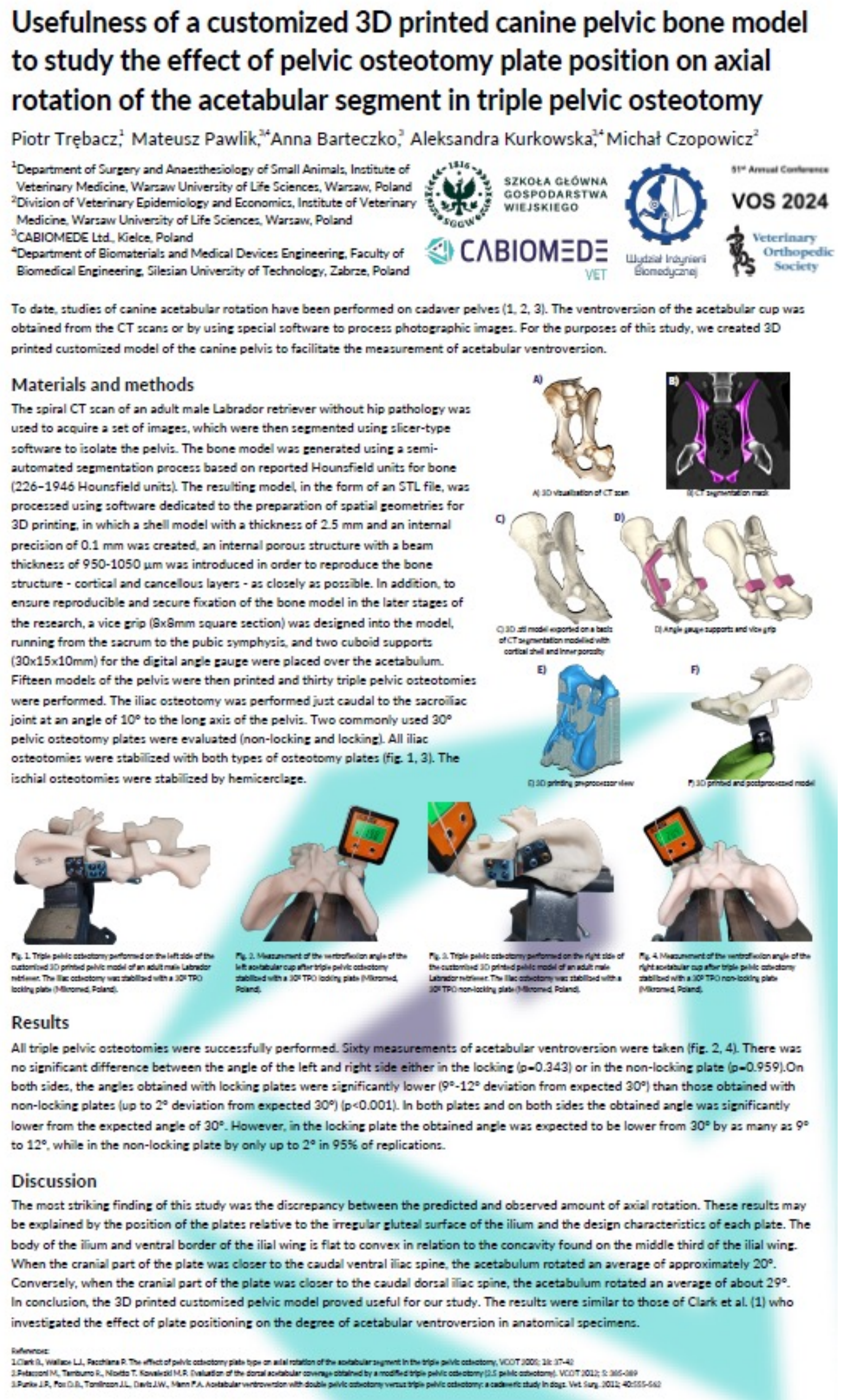

Usefulness of a customized 3D printed canine pelvic bone model to study the effect of pelvic osteotomy plate position on axial rotation of the acetabular segment in triple pelvic osteotomy

Piotr Trębacz[1], Mateusz Pawlik[3,4], Anna Barteczko[3], Aleksandra Kurkowska[3,4], Michał Czopowicz[2]

[1]Department of Surgery and Anaesthesiology of Small Animals, Institute of Veterinary Medicine, Warsaw University of Life Sciences, Warsaw, Poland
[2]Division of Veterinary Epidemiology and Economics, Institute of Veterinary Medicine, Warsaw University of Life Sciences, Warsaw, Poland
[3]CABIOMEDE Ltd., Kielce, Poland
[4]Department of Biomaterials and Medical Devices Engineering, Faculty of Biomedical Engineering, Silesian University of Technology, Zabrze, Poland

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To date, studies of canine acetabular rotation have been performed on cadaver pelves (1, 2, 3). The ventroversion of the acetabular cup was obtained from the CT scans or by using special software to process photographic images. For the purposes of this study, we created 3D printed customized model of the canine pelvis to facilitate the measurement of acetabular ventroversion.

Materials and methods

The spiral CT scan of an adult male Labrador retriever without hip pathology was used to acquire a set of images, which were then segmented using slicer-type software to isolate the pelvis. The bone model was generated using a semi-automated segmentation process based on reported Hounsfield units for bone (226–1946 Hounsfield units). The resulting model, in the form of an STL file, was processed using software dedicated to the preparation of spatial geometries for 3D printing, in which a shell model with a thickness of 2.5 mm and an internal precision of 0.1 mm was created, an internal porous structure with a beam thickness of 950-1050 µm was introduced in order to reproduce the bone structure - cortical and cancellous layers - as closely as possible. In addition, to ensure reproducible and secure fixation of the bone model in the later stages of the research, a vice grip (8x8mm square section) was designed into the model, running from the sacrum to the pubic symphysis, and two cuboid supports (30x15x10mm) for the digital angle gauge were placed over the acetabulum. Fifteen models of the pelvis were then printed and thirty triple pelvic osteotomies were performed. The iliac osteotomy was performed just caudal to the sacroiliac joint at an angle of 10° to the long axis of the pelvis. Two commonly used 30° pelvic osteotomy plates were evaluated (non-locking and locking). All iliac osteotomies were stabilized with both types of osteotomy plates (fig. 1, 3). The ischial osteotomies were stabilized by hemicerclage.

A) 3D visualisation of CT scan

B) CT segmentation mask

C) 3D .stl model exported on a basis of CT segmentation modelled with cortical shell and inner porosity

D) Angle gauge supports and vice grip

E) 3D printing preprocessor view

F) 3D printed and postprocessed model

Fig. 1. Triple pelvic osteotomy performed on the left side of the customized 3D printed pelvic model of an adult male Labrador retriever. The iliac osteotomy was stabilized with a 30° TPO locking plate (Mikromed, Poland).

Fig. 2. Measurement of the ventroflexion angle of the left acetabular cup after triple pelvic osteotomy stabilized with a 30° TPO locking plate (Mikromed, Poland).

Fig. 3. Triple pelvic osteotomy performed on the right side of the customized 3D printed pelvic model of an adult male Labrador retriever. The iliac osteotomy was stabilized with a 30° TPO non-locking plate (Mikromed, Poland).

Fig. 4. Measurement of the ventroflexion angle of the right acetabular cup after triple pelvic osteotomy stabilized with a 30° TPO non-locking plate (Mikromed, Poland).

Results

All triple pelvic osteotomies were successfully performed. Sixty measurements of acetabular ventroversion were taken (fig. 2, 4). There was no significant difference between the angle of the left and right side either in the locking ($p=0.343$) or in the non-locking plate ($p=0.959$).On both sides, the angles obtained with locking plates were significantly lower (9°-12° deviation from expected 30°) than those obtained with non-locking plates (up to 2° deviation from expected 30°) ($p<0.001$). In both plates and on both sides the obtained angle was significantly lower from the expected angle of 30°. However, in the locking plate the obtained angle was expected to be lower from 30° by as many as 9° to 12°, while in the non-locking plate by only up to 2° in 95% of replications.

Discussion

The most striking finding of this study was the discrepancy between the predicted and observed amount of axial rotation. These results may be explained by the position of the plates relative to the irregular gluteal surface of the ilium and the design characteristics of each plate. The body of the ilium and ventral border of the ilial wing is flat to convex in relation to the concavity found on the middle third of the ilial wing. When the cranial part of the plate was closer to the caudal ventral iliac spine, the acetabulum rotated an average of approximately 20°. Conversely, when the cranial part of the plate was closer to the caudal dorsal iliac spine, the acetabulum rotated an average of about 29°.
In conclusion, the 3D printed customised pelvic model proved useful for our study. The results were similar to those of Clark et al. (1) who investigated the effect of plate positioning on the degree of acetabular ventroversion in anatomical specimens.

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