



Photogrammetry and 3D prototyping: A *low-cost* resource for training in veterinary orthopedics

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ABSTRACT: *Rapid prototyping (RP) is an innovative technology that allows one to obtain a prototype of a mold quickly and accurately from a virtual model. This study aimed to establish the use of photogrammetry and 3D prototyping for the production of bone biomodels of the canine species for training in orthopedic techniques in veterinary medicine. Virtual bio-modelling was performed by the photogrammetry technique with commercial anatomical pieces, and physical biomodelling was performed by 3D printing. Osteotomies were performed on the biomodels that served as platforms for osteosynthesis of the femur and ileum, and the final product was not associated with a risk of biological contamination, was able to support special orthopedic materials, and was used for training and surgical planning. We concluded that the use of photogrammetry and RP for the production of bone biomodels of the canine species enabled techniques for fracture reduction to be performed with the use of special instruments, enabling training in the area of veterinary orthopedics in an economically viable manner with an alternative to experimental animals.*

Key words: *physical biomodelling, virtual biomodelling, 3D printing.*

Fotogrametria e prototipagem 3D: Um recurso *low-cost* para treinamento em ortopedia veterinária

RESUMO: *A prototipagem rápida (PR) é uma tecnologia inovadora que permite obter o protótipo de um molde com rapidez e precisão a partir de um modelo virtual. Esse estudo objetivou estabelecer o uso da fotogrametria e prototipagem 3D para a produção de biomodelos de ossos da espécie canina, para treinamento em técnicas ortopédicas em Medicina Veterinária. Utilizou-se a biomodelagem virtual através da técnica de fotogrametria de peças anatômicas comerciais e a biomodelagem física através de impressão 3D. Foram realizadas osteotomias nos biomodelos, que serviram para realização de osteossínteses de fêmur e íleo, sendo que o produto final não ofereceu risco de contaminação biológica, foi resistente para suportar matérias especiais ortopédicas, servindo para o treinamento e planejamento cirúrgico. Concluímos que a utilização da fotogrametria e PR para a produção de biomodelos de ossos da espécie canina, permitiu a execução de técnicas para redução de fraturas e capacitação na utilização de instrumentais especiais, possibilitando treinamento na área de ortopedia veterinária de maneira economicamente viável e uma alternativa em substituição aos animais de experimentação.*

Palavras-chave: *biomodelagem física, biomodelagem virtual, impressão 3D.*

Rapid prototyping (RP) is a technology that has been recently developed and enables one to quickly and accurately prototype a mold from a virtual model generated in a computer-aided design program, enabling the direct transformation of projects into end products for various uses (BORDELO, 2018; SEARS et al., 2016).

Virtual bio-modelling is required to obtain a digital model that reproduces the morphological characteristics of a structure, and the image can be enhanced through specific software. Prototyping, or physical bio-modelling, is the process of obtaining physical biomodels through 3D printing (SILVA & GAMARROSADO, 2014).

The 3D modeling software programs use computed tomography (CT), magnetic resonance imaging

or photogrammetry imaging data to construct a facsimile structure (FREDIEU, 2015; BORDELO et al., 2018). Photogrammetry is a low-cost technology that is used to render 3D models from a set of images of a 360° view of the same object for RP (FAU et al., 2016).

The availability of these materials reduces the need for actual anatomical models to facilitate teaching, as the replicate models can instead be used to educate university students, promoting a good understanding and allowing students to visualize real structures with tangible models (SILVA & GAMARROSADO, 2014; FREDIEU et al., 2015; REIS et al., 2017).

This tool can also be used by educators to clarify different treatment options to patients,

reducing the time to surgery and thus facilitating operative planning by simulating the structures to be addressed (FREDIEU et al., 2015; SINGHAL et al., 2016). Alternative methodologies to animal studies are a necessity within the scientific community, with the 3Rs program (reduce, recycle and reuse), a goal to be achieved in research, and met through the use of biomodels (FREDIEU et al., 2015; SINGHAL et al., 2016; BORDELO et al., 2018).

Over the years, in veterinary medicine, it has always been common practice to perform training and teach surgical techniques on corpses or live animals, causing harm or death to the animals, which can even make it impossible to study the corpse or animal. However, in recent years, in universal veterinary education, it has become more common to focus on the surgical procedure practices most commonly performed in private practice, leading to the need for alternative biomodels to meet the demand (GRIFON et al. 2000).

However, the applicability of biomodels produced by 3D printing in practical classes and veterinary training has not been explored in depth, and one of the limitations is the availability of digital 3D models due to the cost of CT or MRI images (FREDIEU et al., 2015; SINGHAL et al., 2016; REIS, 2017). Thus, photogrammetry is an accessible alternative to other 3D data acquisition methods and has the advantages of being portable and adaptable to various environments. This study aimed to establish the use of photogrammetry and RP for the production of canine bone bio-models for training orthopedic techniques in veterinary medicine.

Commercial anatomical models from the veterinary section of the company SYNBONE are composed of porous rigid polyurethane, suspended by 0.20 mm nylon thread, and have an adapted wooden support (Figure 1A). Photos were obtained with overlapping images so that the software could identify the location of each image, allowing the 3D rendering of the chosen model. The environment was controlled with artificial illumination over 2 incident points on the objects to minimize shaded regions in the pieces. A white base with colored markings was fixed under the suspended region to better guide the software algorithm, as recommended by EVIN et al. (2016).

To capture the images, a Nikon D510 camera with an AF-S NIKKOR 18-55 mm focal lens was used, and close-up photograph sequences to capture a 360° view of each piece were obtained. No fixed values were set for the camera's shooting speed and diaphragm.

Each set of images was uploaded and rendered by the educational trial version of Autodesk ReCap Photo, which allows up to 100 images per object to be uploaded. After the overlapping points are analyzed and the similarity between the images is identified, the program generates a high resolution 3D model in a polygon mesh so that the file can later be converted to STL (Stereolithography) format (Figure 1B). Educational version of AutoCAD software was used to smooth the edges, mirror the object, and perform Boolean operations.

Using open source MakerWare software, the position and overall size of the part was previously specified, allowing replication of the same structure in varying sizes. For all models, a 1.75 mm diameter PLA (Polylactic Acid) filament was used with the following specifications: support raft, 40% fill, 3 detailing layers, 200 micron layer thickness, extruder nozzle at 195 °C with extrusion speed of 30 mm/s and nozzle travel speed at 30 mm/s. After configuring the print settings, the file was saved in .x3 g format on an SD card and attached to the open source 3D printer (Figure 1C) to perform the RP.

The piece was manually finished with wood sandpaper on the protrusion areas (Figure 1D), and the fractures were created, which later served as the platform on which the orthopedic techniques were performed to reduce various fractures, including an apophyseal avulsion fracture of the great trochanter, an oblique fracture of the ilium, a comminuted fracture of the femur and a long fracture of the oblique axis. For these corrections, it was possible to use all necessary equipment, such as steel wire for cerclage, sharp reduction tweezers, surgical drills, surgical screws, a fixation plate, and a fixation plate bender.

We confirmed that the final product presented no risk of biological contamination and was able to support special orthopedic materials so that it could be used for training and surgical planning and allowed us to create the desired fracture and its surgical correction. Physical anatomical models of biological origin are commonly used, but they have limitations regarding the costs, storage requirements, deterioration of the structures, safety and maintenance, and business models may be unrealistic and economically unviable. It is necessary to use several animals to achieve satisfactory results in surgical training, leading to a continuous demand for animals and/or corpses (GRAUVOGEL et al., 2012; FREDIEU et al., 2015).

Bio-models are valuable for enabling a full-scale prototype to be created and handled,

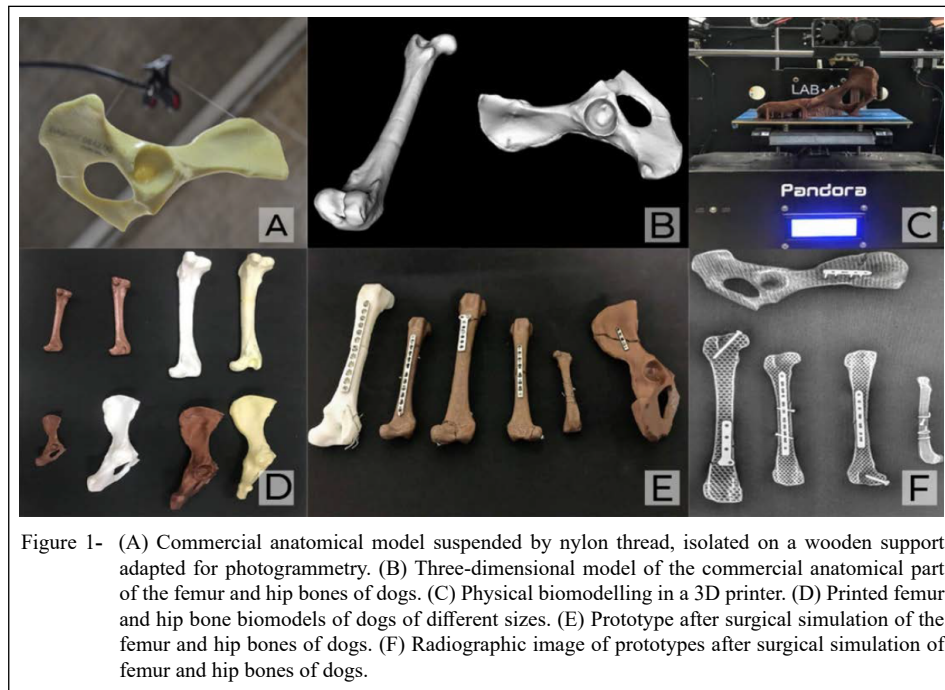


Figure 1- (A) Commercial anatomical model suspended by nylon thread, isolated on a wooden support adapted for photogrammetry. (B) Three-dimensional model of the commercial anatomical part of the femur and hip bones of dogs. (C) Physical biomodelling in a 3D printer. (D) Printed femur and hip bone biomodels of dogs of different sizes. (E) Prototype after surgical simulation of the femur and hip bones of dogs. (F) Radiographic image of prototypes after surgical simulation of femur and hip bones of dogs.

as performed in this study; different orthopedic techniques, including diaphyseal and metaphyseal osteotomies of the femur and hip bones and the performance of respective osteosynthesis through the application of plates and screws, can be exercised with realistic models that create a level of difficulty of execution analogous to that with biological models, and the surgical alignment accuracy and final aesthetic quality can be evaluated by radiographic images (SILVA & GAMARRAZADO, 2014; BORDELO, 2018).

This study eliminated the need for animals for surgical training using alternative measures, and these approaches help to reduce dependence on older modeling methods, thereby promoting animal welfare and extending resource life (BOYD; CLARKSON; MATHER, 2015).

The photogrammetry technique used in this study is a highly recommended method for 3D data acquisition. Digital models can be manipulated to enable medical surgeons to analyze, plan and practice complex and varied techniques on the same type of case in different models (GRAUVOGEL et al., 2012).

In this study, it is highly recommended that users adapt the protocols to each situation encountered, which is in accordance with a study by FREDIEU et al. (2015); the authors suggested

that resolution and accuracy depend on the camera settings, photographer's experience and the functionality of the chosen software.

The use of low cost printers and the use of free software for the acquisition of a 3D model allowed the creation of the desired model; the software can be run on conventional computers, as it does not require advanced editing programs, thus contributing to the reduction of costs for obtaining the biomodel and aiding in the popularity of the technique as an example in this study. Educational institutions can maintain a library of biomodel models, both physical and digital models, reducing the costs of acquiring didactic material and reducing the need for original models (SILVA & GAMARRAZADO, 2014; FREDIEU et al., 2015).

The RP is economically viable due to the low cost of raw materials and low cost of production (CHEN et al., 2017). Costs are related to the choice of the printer model and filament used. A limiting factor of RP is the speed of printing. In this study, the parts had an average printing time of 7 hours, and the delay in production was financially justified by the success and reduction of surgical time, which was acquired by previous training (HESPEL et al., 2014).

We concluded that the use of photogrammetry and RP for the production of canine bone bio-models enabled surgical training in

techniques for fracture reduction and training in the use of special instruments, enabling veterinarians and students to train in the area of veterinary orthopedics in an economically viable manner with an alternative to experimental animals.

DECLARATION OF CONFLICT OF INTERESTS

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHOR'S CONTRIBUTIONS

The authors contributed equally to the manuscript.

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