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Communication

[*Comunicação*]

Computational development of a precise drilling guide for implant insertion in canine vertebral bodies

[Desenvolvimento computacional de um guia cirúrgico de perfuração precisa para inserção de implantes em corpo vertebral de cães]

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Surgical treatment of vertebral body stabilization of canine spines includes fixation and stabilization of fragments to allow bone and ligament healing. (Watine *et al*., 2006). Rigid spinal fixation methods can be obtained by different techniques using pins or screws associated with polymethyl methacrylate, vertebral body plates and external skeletal fixation. The most substantial bony purchase is achieved by placing implants into the vertebral bodies (Hettlich, 2017).

The insertion of implants into the vertebral body is placed either through the conventional use of anatomical references or free-hand technique. The techniques are not completely accurate considering that during the surgical procedure, only the implant entry point is visible (Vecina *et al*., 2008). Several complications are attributed to this method, such as the invasion of the vertebral canal, neurological damage, injury to large vessels and failure to properly position the implant (Tran *et al*., 2017).

To promote safer implant placement and reduce the occurrence of iatrogenic lesions, surgical guides developed using computer tools and rapid prototyping have been proposed in human dentistry and medicine (Di Giacomo *et al*., 2005). The interest in the production of three-dimensional printing of drill guides to target a safe drilling corridor in veterinary neurosurgery has been growing. Technique benefits include accuracy, reduced surgical time and reduced morbidity (Guevar *et al*., 2020).

There are few studies that have focused on use of vertebral body implant placements (Guevar *et al*., 2020). The differences in accuracy between different 3D printed drill guide designs and specific design recommendations have not been reported (Guevar *et al*., 2020). Recent studies showed promising results with patient-specific surgical guides: Fujioka *et al*. (2020) concluded that new drill guide template system was useful for accurate intraoperative screw positioning in lumbosacral fixation surgery for small dogs. Guevar *et al*. (2020) demonstrated that unilateral and bilateral 3D animal-specific drill guide designs are accurate and safe for instrumentation in the thoracic and lumbar vertebral column of dogs in an *ex-vivo* model.

In this study we aimed to describe a novel patient specific computational design method of a drilling guide for the insertion of implants in the canine vertebral bodies

The study was conducted in a virtual environment, using computational tools to design surgical drilling guides for the cervical, thoracic,

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and lumbar vertebral column of dogs. The first stage required computed tomographic (CT) data of the cervical, thoracic, and lumbar segments of the canine spine. Computed tomographic files of patients that underwent examination for reasons unrelated to the study were used (1-5 mm slice thickness, Toshiba Asteion (1-slice) CT apparatus, Visiovet Veterinary Diagnostic Center, Belo Horizonte, Brazil). Data were collected from small, medium, and large-sized dogs to compare the adaptation of the guide to patients of different sizes.

DICOM computed tomographic image files were analyzed using an image software (InVesalius), allowing the creation of 3D virtual models from two-dimensional images obtained by computed tomography. Using the image segmentation feature of the program, the osseous structures were isolated and selected by setting the threshold voxel intensity between 226 and 1398. The segmentation feature is used to select a specific type of tissue from the image by configuring a mask - image with the selected region colored and superimposed on the original image. With the segmentation mask configured, it is possible to generate a 3D surface corresponding to the images under study. The 3D volume model was exported in the stereolithography (STL) format to a mesh modeling program (MeshMixer).

In MeshMixer, the STL files were edited to remove unnecessary details of the geometry, such as the scapula, ribs, pelvis, viscera fragments, and the rail used to position the patient (Fig. 1-A). The software was also used to isolate the vertebrae of interest, turn the mask set into a solid set, create a surface mesh, and reduce the number of mesh vertices. Upon completion of the described steps, the model was ready to be exported and worked into a solid, readable, and editable STL modeler program (Fig. 1-B).

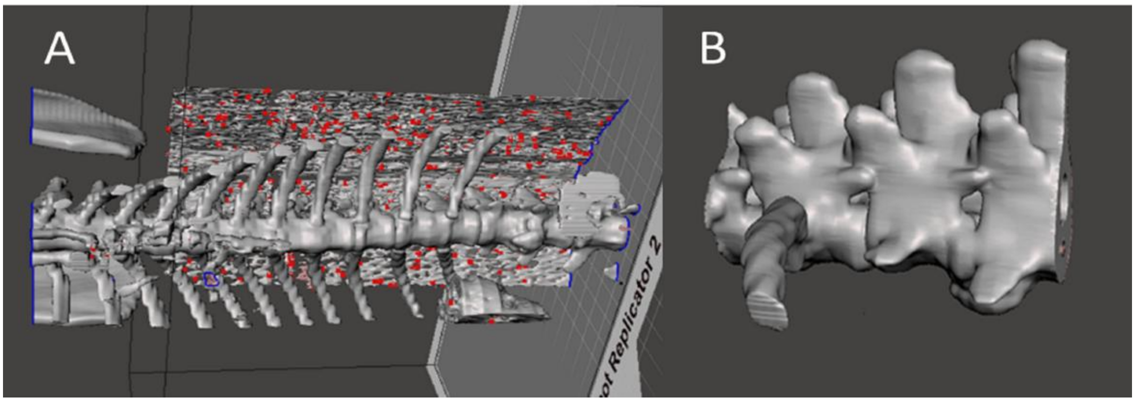

Figure 1. Dog: virtual model of a thoracolumbar spine (Meshmixer software). Note the gross model before the removal of unspecific parts (A) and after the vertebrae of interest has been isolated (B).

In the assembly area of the solid modeling program (Solidworks), a sagittal plane was created perpendicular to the spinous process, approximately in the center of the vertebra of interest, to introduce two lines that were used as assembly guides (Fig. 2).

The construction of the basic components of the drilling guide allows adjustment of the device to patients of different sizes. The surgical guide was developed to allow a perfect fit on the external surface of the vertebra and the restriction of six degrees of freedom (three translations and three rotations in the X, Y and Z axes).

The basic components of the surgical guides were developed in a solid two-piece modeler as separate clamping and perforation guide components, respectively. The guide attachment member had three arms for engaging the spinous and/or transverse process (Fig. 3-A). The perforation guide component had a hole, whose diameter could be adjusted according to the size of the patient (Fig 3-B).

For guide vertebra assembly operation, the files for the vertebra as well as those for the fixation and perforation guide were selected. An assembly line was introduced into the hole center of the drill guide and correlated with the vertebral assembly line for correct positioning. The fixation component was positioned over the transverse process in the cervical vertebrae and in the spinous process in the thoracic and lumbar vertebrae.

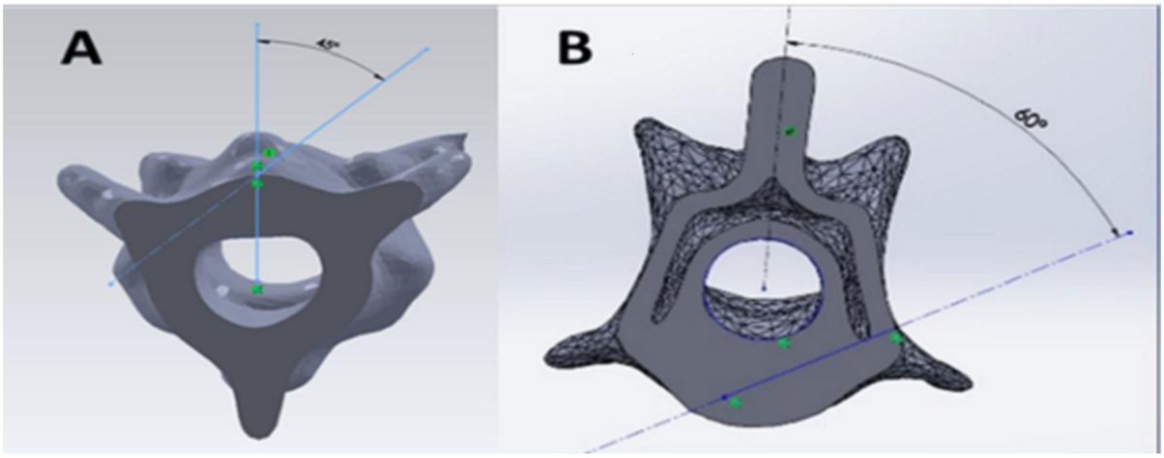

Figure 2. Dog: transversal sections of vertebral models. Introduction of assembly and perforation lines in the cervical (A) and lumbar (B) vertebrae.

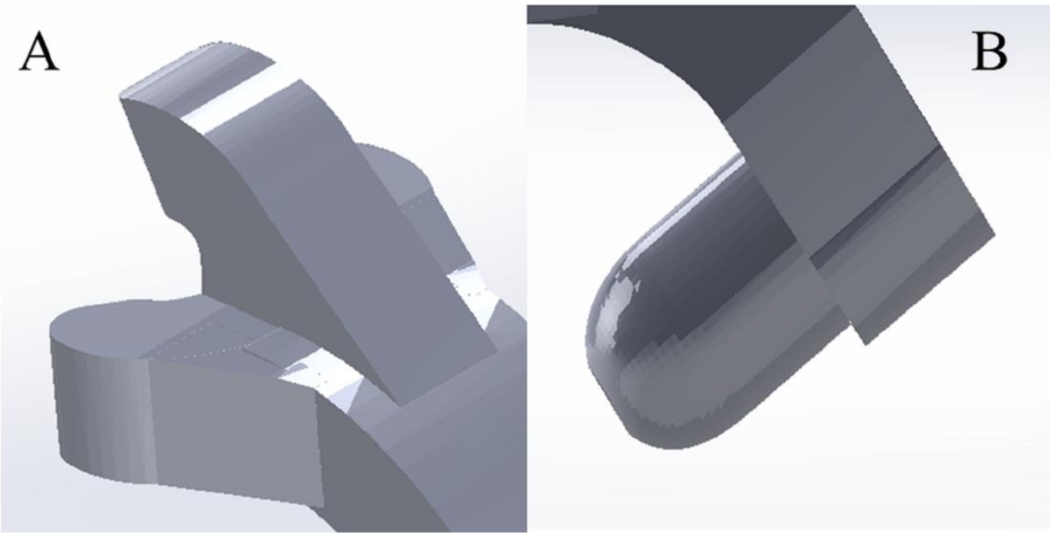

Figure 3. Basic components of the surgical guides: clamping component model lateral oblique views (A) and perforation guide component model in lateral views (B).

After correctly positioning the two parts, a connecting component was inserted between the clamping component and the perforation component with subsequent use of a joining tool, thereby finalizing the development of a single final patient specific part for the vertebra.

The final step of the surgical guide customization process included removing the intersection area from the vertebra in the guide to ensure a perfect fit (a Boolean operation), enabling the model to be prepared for prototype manufacture.

In InVessalius, some CT files configured within the automatic segmentation threshold named "bone" showed regions of failure in the 3D reconstruction, and it was necessary to configure the mask in a personalized way.

Non-anatomical hollow regions were identified due to possible failures of the 3D reconstruction, these regions were corrected from the manual filling of the mask in the InVessalius program. This step was required the performance of manual segmentation of the mask of each slice of the exam. Thus, we chose to use the automated tool “Hallow” of the Meshmixer to identify and fill non-anatomical hollow regions. The mesh modeler made possible to manipulate the basic geometry of the fixation and scale drilling components to suit the size and specific anatomy of the vertebra for different dogs. Changes in the basic geometry scale were performed symmetrically on the x, y, and z axes and in a few cases, only in one or two directions. It was not possible to fix the base of the guide fixation component in the spinous process of the T10 and some T11 vertebrae due to their slanted or short shape.

Watine *et al*. (2006) defined the characteristics of optimum implantation corridors in canine vertebral bodies C2 to C7 and T10 to S1, using computed tomography examination. The definition of the perforation line in the present study was based on characterizing each corridor by an insertion point, a mean angle with respect to the sagittal plane, a width and a depth. The distance between the emergence points of an implant exiting the vertebral body and the structures to be spared is also very important.

The use of a solid modeler permitted the creation of planes perpendicular to the vertebra and inclined in one or two directions for the introduction of assembly/perforation lines. From the basic model of the clamping and perforation components, it was possible to develop surgical guides of different sizes and shapes. After positioning the fastener, it was possible to insert one or more drilling guides for surgical planning, making it possible to develop parts with two or more perforation components in different planes and directions (Fig. 4). The guides were positioned according to the surgical access indicated for the vertebral segment. For the cervical vertebrae, the guides were positioned on the ventral side of the vertebra, with the clamping component engaged in the transverse process. For the thoracic and lumbar vertebrae, the guides were positioned on the dorsolateral face with the clamping component engaged in the spinous process.

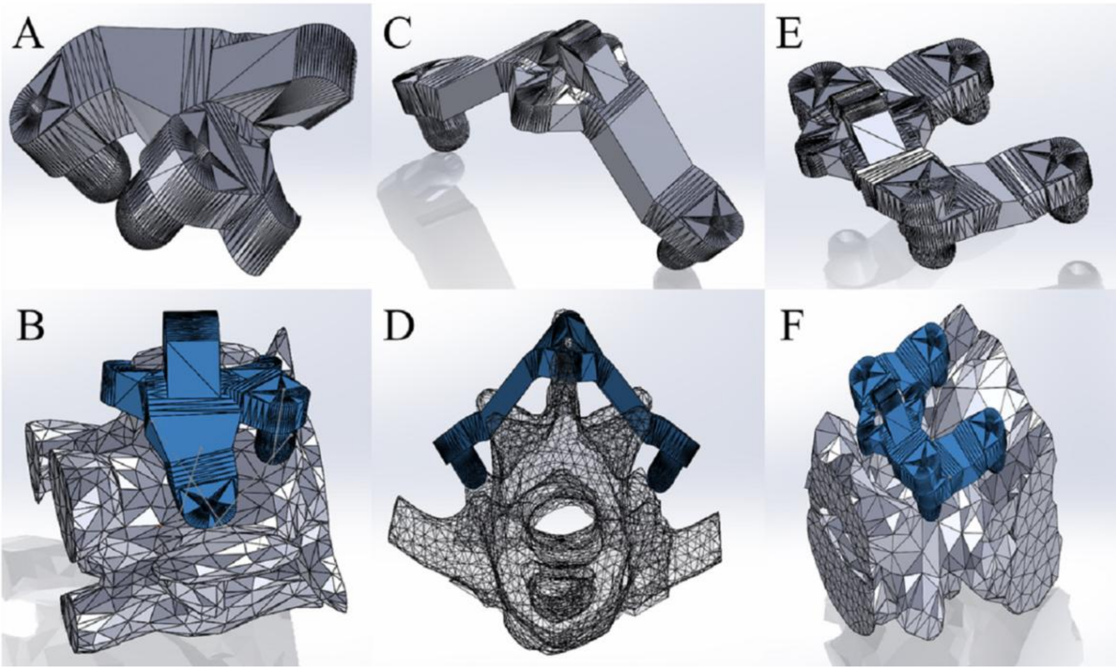

Figure 4. Dog: development of surgical guides with different formats. A) cervical guide with two perforation components in different planes and directions and B) assembly in cervical vertebrae. C) Thoracic guide with two perforation components in different planes and directions and D) assembly in thoracic vertebrae. E) Lumbosacral guide with four perforation components in different planes and directions and F) assembly in lumbar vertebrae.

A very attractive aspect of this method, therefore, resides in the creation of animal-specific, rapidly created, inexpensive and safe drill guides. Limitations include the need of 3D design software training, the requirement for clean bone preparation, and the production of debris intraoperatively (Wilcox *et al.*, 2017). The authors agree that the guide can be rapidly created, and that 3D design software knowledge can have a steep learning curve for those not trained previously.

The limitations reported in the drilling guide model system in the study by Fujioka *et al*. (2018) included the requirement of an almost complete removal of soft tissues from the vertebrae to fit the model (which may compromise the vertebral vascularization). The proposal of the clamping component in the present study, in addition to fulfilling the crimping function, has the characteristic of not creating additional trauma during the surgical procedure; hence, it can be adapted to the site without the need for incision or surgical dissection in addition to those already performed for surgical focus exposure.

The proposed format, which divides the device into two components, not only allowed the correct positioning of the guide in different vertebrae and for different sizes, but also introduced a new range of possibilities for the planning and format of the guide. For example, a clamping component can be associated with two or more perforation components that can have different planes and directions. The use of inclined planes makes it possible to plan perforations with greater bone purchase, not being described in previous studies (Fujioka, 2018, 2020, Di Giacomo, 2005, Guevar *et al*., 2020). The separate basic components allowed the assembling of different guides quickly and with the freedom to adjust the guide as required. Guevar *et al*. (2020) recommended additional studies to establish how to optimize surgical guide design.

Although preliminary, this study developed a novel and innovative surgical guide for implant insertion in the vertebral body with the potential to be a relevant advancement in veterinary neurosurgery techniques. The patent for the guide was requested at the Brazilian Institute of Industrial Property and additional cadaveric studies for its application in clinical cases are underway.

Keywords: *dogs, drill guide, vertebra, patient-specific*

RESUMO

O tratamento cirúrgico de estabilização da coluna vertebral de cães usualmente requer osteossíntese com uso de implantes, como pinos e parafusos. No entanto, as técnicas atuais de inserção de implantes no corpo vertebral não são totalmente precisas e várias complicações são atribuídas ao ato, como invasão do canal vertebral, danos vasculares e neurológicos. Para promover segurança na inserção de implantes e reduzir a ocorrência de lesões iatrogênicas, vem crescendo o interesse na produção de guias de perfuração em neurocirurgia veterinária. Com o objetivo de assegurar maior precisão e acurácia durante a perfuração óssea, foi desenvolvido um novo design *de guia cirúrgico para inserção de implantes em corpo vertebral específico para a anatomia do paciente. A técnica proposta permite determinar o trajeto e o ângulo de perfuração óssea no corredor de implantação de cada vértebra, pela customização da guia e visa reduzir as taxas de complicações, promover precisão no posicionamento de implantes vertebrais e reduzir o tempo cirúrgico.*

Palavras-chave: cães, guia de perfuração, vértebra, paciente-específico

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