

# FINITE ELEMENT ANALYSIS OF PEDICLE SCREW PULLOUT STRENGTH IN TRADITIONAL AND CORTICAL BONE TRAJECTORIES

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**Abstract.** *Pedicle screws are used in the treatment of various spine disorders. The insertion can be made through the traditional trajectory and, recently, through the cortical bone trajectory. Since the screw insertion is a traumatic procedure, it is important to fully understand the interaction between the screws and the vertebra before the surgery. This study compares the fixation strength between both by performing a finite element analysis of the pullout load in both trajectories. The vertebra model is imported from a CT scan. The cortical bone trajectory demonstrated a greater pullout resistance when compared to the traditional trajectory.*

**Keywords:** *Spine; Pedicle screw; Finite element analysis.*

## 1. INTRODUCTION

To properly implant medical devices in patients, it is important to understand how the body behaves from a mechanical point of view. Consequently, it is possible to properly analyze how it will interact with prosthesis, orthosis and/or support medical devices. Internal instruments, such as pedicular screws, which involve a traumatic procedure, may be difficult or impossible to change after being implanted. Thus, techniques for simulating these elements, such as Finite Element Analysis (FEA), are an important step in the characterization of the implant (Goel, 2006). The understanding and characterization of the analysis is also important, so that it can be properly reproduced and its reliability tested (Erdemir *et al.*, 2012).

In the last decades, the use of pedicle screws in spine surgery has been growing. They provide fixation in all three dimensions, as well as greater stability when compared to other fixation methods, and so can be used for correction a myriad of deformities (Deviren *et al.*, 2005). The technique has proved to be safe, as shown in various studies (Brown *et al.*, 1998; Crostelli, Mazza and Mariani, 2012). Common complications include screw misplacement, fracture of the pedicle, screw breakage, loosening of the screw or vertebral canal violation (Crostelli, Mazza and Mariani, 2012).

Recent studies have proposed and tested a new trajectory for the insertion of pedicle screws, the cortical bone trajectory (Matsukawa *et al.*, 2015; Santoni *et al.*, 2009). On it, the screw follows a caudocephalad path in the sagittal plane, and a laterally directed path in the transverse plane, as opposed to the traditional trajectory, which follows the anatomical axis of the pedicle. The cortical trajectory, as the name suggests, is designed to maximize contact of the screw with cortical bone, which tends to increase the resistance of the fixation (Santoni *et al.*, 2009).

The magnitude of the pedicle screws' fixation strength can be made through the analysis of the pullout force. Although it is a simple loading case, it is useful in characterizing the interaction between vertebra and screw (Chatzistergos, Sapkas and Kourkoulis, 2010; Matsukawa *et al.*, 2015). The objective of the present study is to compare the pullout load of the traditional and cortical bone trajectories using FEA.

## 2. METHODS

The software used in the analysis was SimLab (version 14; Altair Engineering). A model of a column was provided based on a STL file, obtained from a computed tomography (CT) of a real patient, by the *Laboratório de Prototipagem Rápida* (LPRA). This model was then imported directly into SimLab, and is shown in Fig. 1. The L4 vertebra was selected as the subject of the present study because it is the lowermost vertebra that is completely represented in the STL file provided.

Due to the resolution of the CT scan, the model was imported as a continuous body, without separation between the vertebrae. To separate the L4 for the analysis, it was first necessary to define the location of its interface with the neighbor vertebrae. A rough outline of this locations is shown in Fig. 1. Based on this, i.e. L4 isolated, the next step was to clean the model, in order to obtain a proper surface. Figure 1 shows the internal surface generated in the CT scan. These are imperfections generated due to the resolution of the scan, and were removed from the model.

With the proper surface defined, the next step was to remove all the errors created during the previous steps (Fig. 2). These include holes left in the surface of the vertebra where it was separated from the column, regions where the removed surfaces intersected with the external surface, and minor defects derived from the original file. After these corrections, the final surface mesh was generated. The surface mesh was made using triangular elements (Tri3 in SimLab) of 1mm average size.

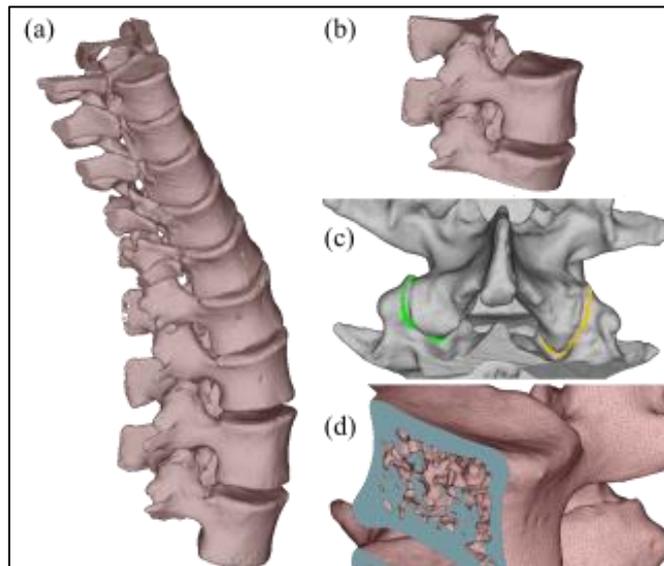


Figure 1. Importing process of CT scan into SimLab. (a) model as imported; (b) cut of the L4; (c) regions where the vertebrae separate; (d) internal surfaces generated in the CT scan.

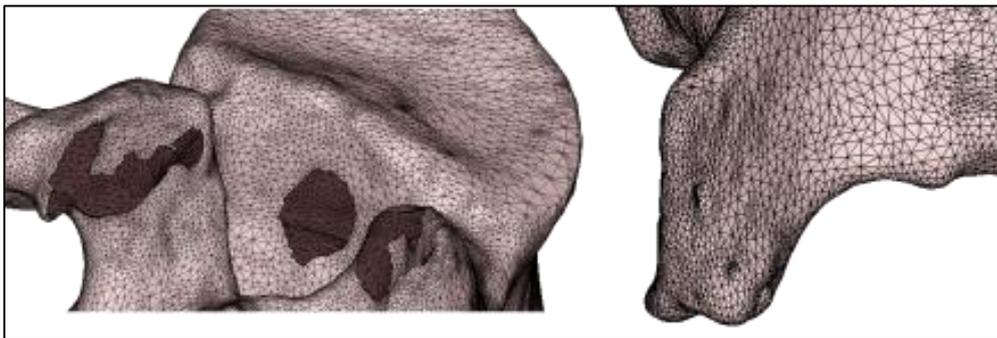


Figure 2. Surface defects in the imported model.

Once the outside surface was defined, the separation of cortical and cancellous bone was made. The cortical region was defined as an inner layer of constant 1mm thickness, and both the cortical and cancellous regions were considered different bodies. The connection between both was defined along with the boundary conditions step, explained later. During modelling, it was considered that the interface between both was a shared surface. This definition guarantees that the nodes of both meshes will coincide and there will be no intersection between elements. Figure 3 shows the layers as defined.

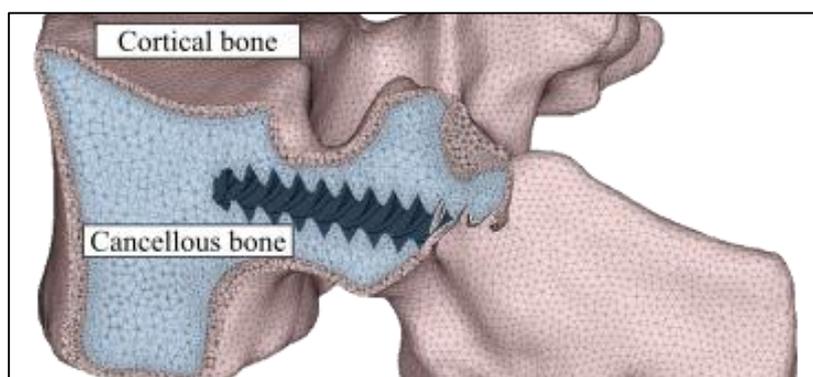


Figure 3. Section view of the final model.

The screw insertion was made by first importing the CAD model into SimLab and generating a surface mesh similar to the vertebra (average 1mm Tri3 elements). It was then positioned inside the vertebra, and with the intersections between both defined, the surface of the screw was duplicated. This process is made in order to have a hole in the vertebra that coincides with the screw thread. The mesh of the hole was also made coincident between the screw and the vertebra. Finally, the solid mesh was generated. It was defined as average sized 1mm tetrahedral elements (TET4 in SimLab). The final model is illustrated in Fig. 3.

The material properties of the bone were defined according to Kim, 2007, and of the screws according to Chao *et al.*, 2008. They are listed in Tab. 1.

Table 1. Material properties used in the model.

Material	Young Modulus [MPa]	Yield Stress [MPa]	Poisson's Ratio
Cortical bone	12000	173	0.3
Cancellous bone	100	3.4	0.2
Ti6Al4V	114000	795	0.3

The vertebra was considered to be fixed in the inferior surface (Kim, 2001, 2007; Schmidt *et al.*, 2007). The contact between the vertebra and the screw is considered as if there was no sliding between both (Kim, 2007). The STICK condition from SimLab was used to achieve this effect. Between cortical and cancellous bone, the contact was considered fixed, with rotation of the nodes transferred. The FREEZE contact in SimLab was used.

The tested trajectories were the traditional and the cortical bone, as illustrated in Fig. 4. The traditional trajectory was defined as parallel to the transversal plane and at a 15° angle to the sagittal plane in the medial direction. The cortical bone trajectory was at a 22° angle to the transversal plane in the cranial direction, and at a 6° angle to the sagittal plane in the lateral direction.

The force was applied in the screws' axial direction in increments of 20N, as suggested by Matsukawa *et al.*, 2015.

The point of failure was defined as the point when the maximum Von Mises stress was greater than the yield stress of the bone.

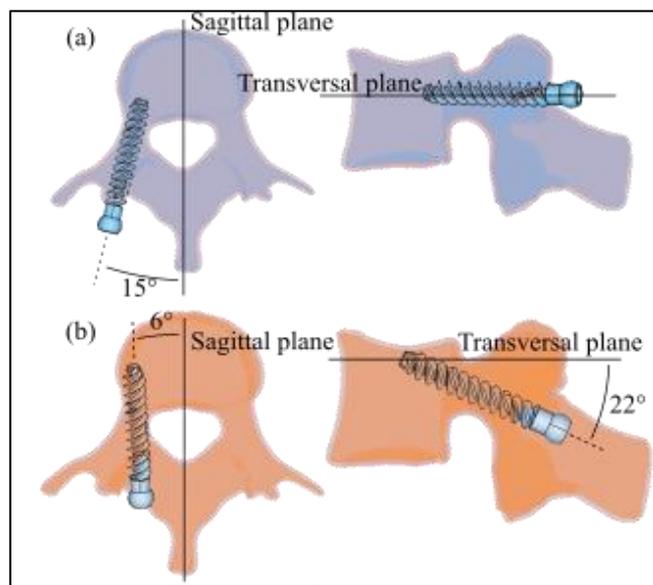


Figure 4. Screw trajectories. (a) traditional trajectory; (b) cortical bone trajectory.

#### 4. RESULTS

In the traditional trajectory, failure occurred when the force reached 460N. At this point, the maximum Von Mises stress in the cancellous region was 3.49MPa. At the point of failure, the maximum Von Mises stress in the cortical region was 65.6MPa, well below the yield stress. These results are shown in in Fig. 5.

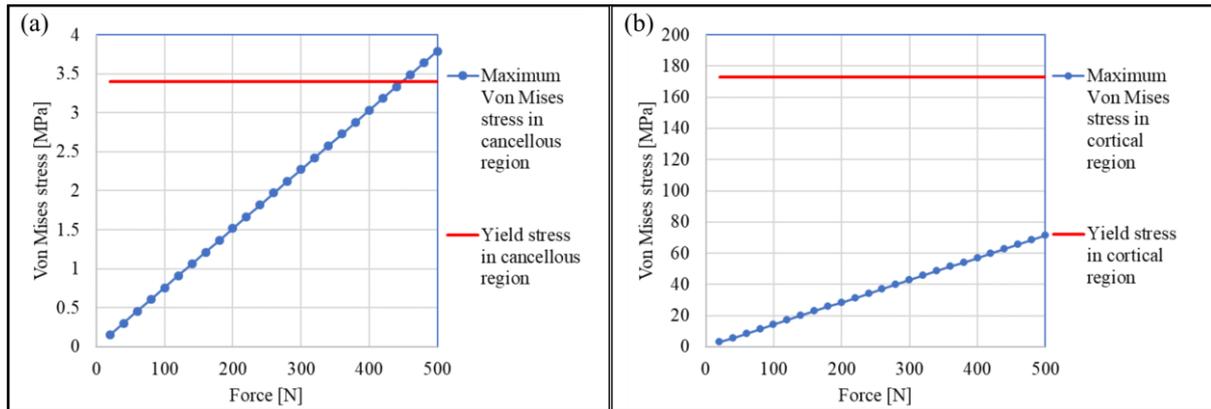


Figure 5. Result from the traditional trajectory pullout test. (a) cancellous region; (b) cortical region.

In the cortical bone trajectory, failure occurred when the force reached 1160N. At this point, the maximum Von Mises stress in the cancellous region was 3.42MPa. At the point of failure, the maximum Von Mises stress in the cortical region was 158MPa, closer to the yield stress when compared to the traditional trajectory. These results are shown in Fig. 6.

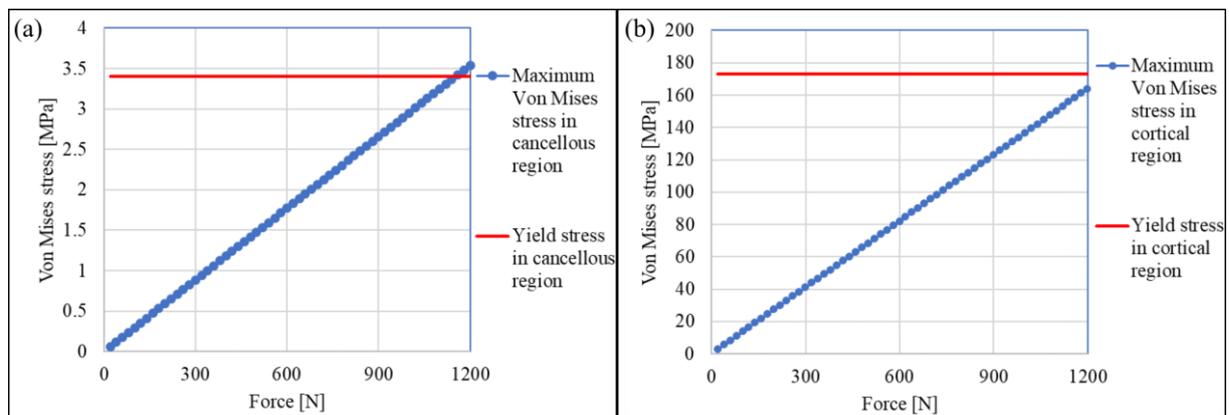


Figure 6. Result from the cortical bone trajectory pullout test. (a) cancellous region; (b) cortical region.

As expected, the cortical bone trajectory was able to resist a greater force than the traditional trajectory. This can be attributed to the fact that it has greater contact area with the cortical bone. As the cortical bone is more rigid than the cancellous bone, smaller deformation, combined with greater yield stress, promotes higher resistance. This is supported by the result shown in Fig. 6, where the stress in the cortical region is closer to the yield stress when compared to the traditional trajectory result. The cortical bone trajectory also goes through a thicker portion of the vertebra, which distributes the stress over a larger volume, further contributing to the resistance of this trajectory.

## 5. CONCLUSIONS

The cortical bone trajectory showed a significant increase in resistance when compared to the traditional trajectory. This result is in accordance with literature, and it is indicative that this is the preferred trajectory. However, in order to properly define its viability, it is necessary to evaluate the difficulty in inserting the screw, as well as how it behaves in a fully instrumented spine.

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## 7. ACKNOWLEDGMENTS

The authors would like to thank CNPq (Process Number: 442138/2016-4 TA) and UCS for the financial support, and Altair Brasil for the support provided.

## 8. RESPONSIBILITY NOTICE

The authors are the sole responsible for the information included in this work.