UNIVERSITY OF MEDICINE AND PHARMACY

"CAROL DAVILA", BUCHAREST

DOCTORAL SCHOOL

NEUROSURGERY

SPINAL INSTRUMENTATION PER PRIMAM IN THE STABILIZATION OF DEGENERATIVE DISEASES OF THE LUMBAR SPINE

ABSTRACT OF THE DOCTORAL THESIS

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2. The fundamental problem of research

Degenerative pathology of the lumbar spine is a major public health problem, characterized by increased prevalence and significant impact on quality of life [1]. Conditions such as herniated discs, lumbar spinal stenosis and spondylolisthesis frequently cause chronic pain, neurological deficit and functional limitation, constituting major indications for stabilization surgeries [2].

In this context, lumbar interbody fusion has become a standard method of treatment, with the objectives of restoring disc height, correction of sagittal alignment and segmental stabilization [3]. However, despite technological and surgical advances, interbody implants used in these procedures continue to have important limitations. Complications such as subsidence, implant migration and pseudarthrosis persist at significant rates, affecting clinical outcomes and sometimes requiring reinterventions [4].

The fundamental problem addressed in this thesis is to identify the biomechanical limitations of current interbody implants and to evaluate how their design influences the load distribution and stability of the spinal construct [5].

3. Hypothesis and objectives of the research

The central hypothesis of the thesis is that optimizing the design of interbody implants, especially by using modular configurations and integrating advanced biomechanical analysis, can lead to a more favorable distribution of stresses and a reduction in the risk of complications, especially subsidence.

Starting from this hypothesis, the following main objectives have been formulated:

- detailed analysis of the anatomy and biomechanics of the lumbar spine relevant to intercorporeal reconstruction;
- critical assessment of lumbar degenerative pathologies and indications for surgical treatment;
- identification of limitations of interbody implants used in current practice;
- investigating the influence of design parameters on biomechanical behavior;
- development of conceptual models of implants, with a focus on modular configurations;
- the use of finite element analysis (FEA) to simulate biomechanical behaviour;
- correlation of theoretical results with clinical implications.

4. Research methodology

The methodology used in this thesis is interdisciplinary, combining theoretical analysis, literature review and computational modeling [6].

The three-dimensional models developed by CAD were analyzed using the finite element method (FEA), a technique widely used in the biomechanical evaluation of spinal implants [7–8].

In the first stage, an extensive analysis of the literature on the anatomy, biomechanics and pathology of the lumbar spine was carried out, as well as the surgical techniques and implants used in interbody fusion.

In the next step, three-dimensional models of implants were developed using computer-aided design (CAD) techniques. These models were then analysed using the finite element method (FEA), which allows the biomechanical behaviour of structures to be simulated under different loading conditions.

The AEF analysis allowed the evaluation of key parameters, such as:

- stress distribution;
- structural displacements;
- safety factors;
- areas of stress concentration.

This method offers the advantage of virtual implant evaluation prior to experimental or clinical validation, reducing the cost and time required for development Figure 1.

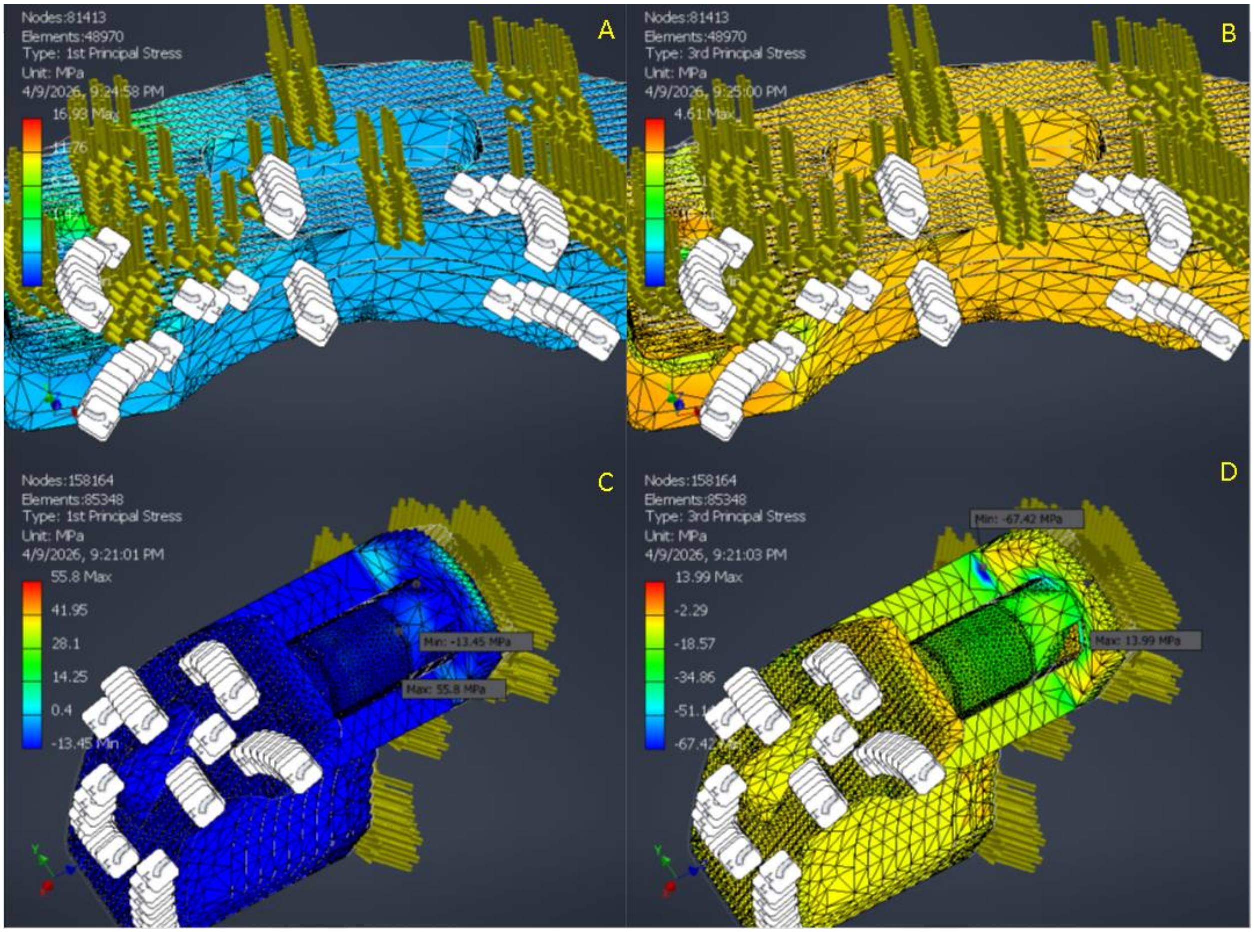

Figure 1. Comparative distribution of main stresses in modular configurations of 8 mm and 18 mm under compressive load. The FEA contours show lower and predominantly compressive values in the 8 mm configuration (σ_1 max: 16.93 MPa; σ_3 min: -29.93 MPa), compared to the 18 mm configuration, which has significantly higher and localized stresses in the upper load transfer area (σ_1 max: 55.8 MPa; σ_3 min: -67.42 MPa). Overall, the extended configuration is subject to higher mechanical demands than the compact one.

5. General part

The first part of the thesis is dedicated to the anatomical, physiological and biomechanical foundations of the lumbar spine.

It is highlighted that the lumbar spine is a complex biomechanical system, in which the intervertebral discs play an essential role in the distribution of loads, and the facet joints and ligaments contribute to stability. Sagittal alignment, especially lumbar lordosis, is essential for maintaining biomechanical balance.

The main degenerative pathologies are analyzed, including:

- lumbar disc herniation, characterized by protrusion of the nucleus pulposus and compression of nerve structures;
- lumbar spinal stenosis, caused by narrowing of the vertebral canal and foramina;
- Spondylolisthesis, defined by the sliding of a vertebral body.

The importance of clinical-imaging correlation and appropriate patient selection for surgical treatment is emphasized.

The biomechanical mechanisms involved in disc degeneration and the appearance of neurological symptoms are also analyzed, as well as the role of genetic and degenerative factors.

6. Personal Contributions

6.1. Personal contributions focus on interbody implants and their biomechanical behavior.

The first study of the thesis evaluated the clinical outcomes and factors associated with the duration of hospitalization in patients undergoing surgery for degenerative lumbar pathology, most of the cases being treated by instrumented fusion. The analysis demonstrated that the duration of postoperative hospitalization was generally short, with a median of about three days, suggesting the effectiveness of perioperative management. In the multivariate model, early postoperative neurological changes were identified as the main factor associated with prolonged hospitalization, while variables such as age had only a marginal influence, and gender, obesity, diabetes, or the type of cage used were not significant predictors. Although the neurological changes were in most cases transient, their presence emphasizes the importance of careful monitoring in the postoperative period. These results contribute to the understanding of the clinical factors influencing early recovery and provide a framework for optimizing perioperative management strategies in lumbar spinal surgery Figure 2.

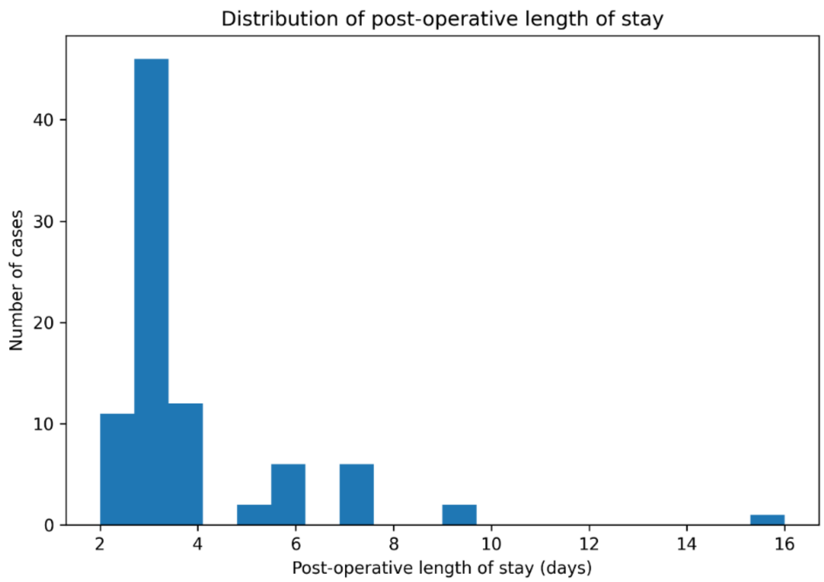

Figure 2. Distribution of postoperative hospitalization duration.

The second study aimed to develop and preliminary biomechanical evaluation, through CAD modeling and finite element analysis, of a modular cage-like prosthetic construction, analyzing how height variations influence stress distribution, deformation and structural stability of the implant [9–11].

It is highlighted that the design of the implant directly influences:

- load distribution at the end board level;
- segmental stability;
- the risk of subsidence and migration.

The main characteristics of the implants are analyzed:

- size and footprint;
- lordotic angle;
- material (titanium, PEEK);
- positioning in the disc space.

The advantages and limitations of extendable and static cages are discussed, as well as the role of modern materials and porous surfaces in osseointegration.

A central element of the research is the analysis of the modular cage concept. It offers important theoretical advantages, such as:

- reduction of insertion forces;
- more uniform distribution of burdens;
- possibility of intraoperative adaptation.

Through FEA analysis, different implant configurations are evaluated, highlighting how geometric changes influence biomechanical behavior Figure 3.

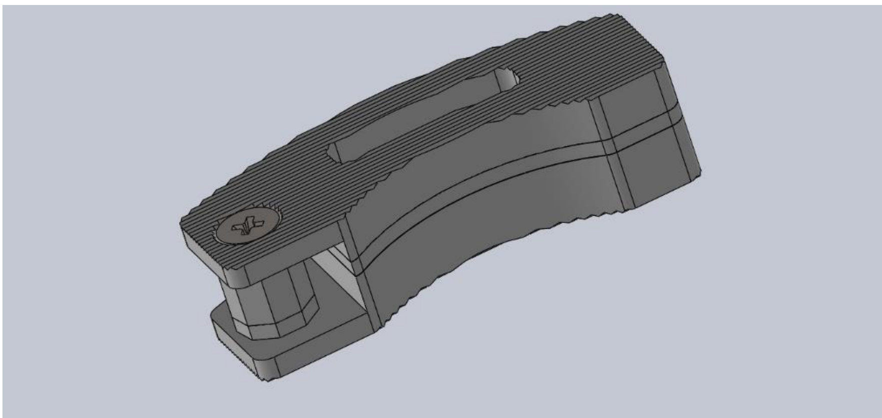

Figure 3. The 8 mm configuration of the modular, cage-like prosthetic construction as seen when fully assembled: three-dimensional CAD representation of the entire 8 mm construction after complete assembly. This image represents the close configuration of the device; These include the terminal parts (upper and lower) of the construction, the central fixation path, the curved shape formed by the contact between the end plate and the lamella, and the dentures on the outer surface of the construction, which have been designed to provide additional initial mechanical stability to the implant-bone interface.

The results show that:

- implants with a larger footprint reduce the risk of subsidence;
- the anterior positioning favors the restoration of lordosis, but can increase stress on the end plates;
- Modular configurations can reduce stress concentrations but introduce additional biomechanical complexity.

7. Conclusions and personal contributions

The results confirm that the design of interbody implants significantly influences stress distribution, stability and subsidence risk, in accordance with the existing biomechanical literature [12–13].

The main conclusions are:

- the distribution of voltages at the level of the end plates is significantly influenced by the geometry of the implant;
- subsidence is correlated with local stress concentrations and material characteristics;
- the restoration of lordosis depends on both the design of the implant and its positioning;
- Modular configurations can provide biomechanical advantages, but they require careful optimization.

The personal contributions of the thesis consist of:

- integrating anatomical, biomechanical and engineering concepts into a coherent model of analysis;
- development of original CAD models for interbody implants;
- application of the AEF analysis for the comparative assessment of different configurations;
- proposing a modular implant concept, analyzed from a biomechanical point of view;
- identification of directions for optimizing the design of implants.

8. Future prospects and directions

The research opens up important perspectives for the development of customized and biomechanically optimized implants. The integration of artificial intelligence into the design and simulation process can allow the automatic generation of optimal configurations.

The following are also required:

- experimental studies to validate the results;
- clinical trials to assess the impact on patients;
- development of more complex biomechanical models, including the biological properties of tissues.

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