

Advanced Structured Materials

Andreas Öchsner
Holm Altenbach *Editors*

Engineering Design Applications IV

Structures, Materials and Processes

 Springer


Advanced Structured Materials

Volume 172

Series Editors

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Common engineering materials are reaching their limits in many applications, and new developments are required to meet the increasing demands on engineering materials. The performance of materials can be improved by combining different materials to achieve better properties than with a single constituent, or by shaping the material or constituents into a specific structure. The interaction between material and structure can occur at different length scales, such as the micro, meso, or macro scale, and offers potential applications in very different fields.

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Editors


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ISSN 1869-8433

ISSN 1869-8441 (electronic)

Advanced Structured Materials

ISBN 978-3-030-97924-9

ISBN 978-3-030-97925-6 (eBook)

<https://doi.org/10.1007/978-3-030-97925-6>

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Preface

Different engineering disciplines such as mechanical, materials, computer and process engineering provide the foundation for the design and development of improved structures, materials and processes. The modern design cycle is characterized by an interaction of different disciplines and a strong shift to computer-based approaches where only a few experiments are performed for verification purposes. A major driver for this development is the increased demand for cost reduction, which is also connected to environmental demands. In the transportation industry (e.g. automotive), this is connected with the demand for higher fuel efficiency, which is related to the operational costs and the lower harm for the environment. A possible way to fulfil such requirements is lighter structures and/or improved processes for energy conversion. Another emerging area is the interaction of classical engineering with the health, medical and environmental sector. This further volume in this series gives an update on recent developments in the mentioned areas of modern engineering design application.

We would like to express our sincere appreciation to the representatives of Springer, who made this volume possible.

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Chapter 1

Biomechanical Study of the Distal Fibula Plate in Isolated Fractures



Juan Alfonso Beltrán-Fernández, Milton Alfredo Pérez-Reyes,
Juan Luis Cuevas-Andrade, Luis Héctor Hernández-Gómez,
and Alejandro González Rebatú y González

Abstract In the present study, a real clinical case of a distal fibula fracture is approached, which was instrumented by means of an LCP plate, which was evaluated at various operating loads to determine its structural mechanical behavior. Using the anatomical and biomechanical data, the process of making a distal fibula plate was replicated and a satisfactory design was achieved that met the functional qualities to arrive at the optimal solution. The theoretical hypothesis given by the theoretical calculations was correct in the sense that the biocompatible titanium alloy plate was the material that was least susceptible to tensile and bending stresses. The tests carried out through the Ansys program showed that the deformation pattern with the models presented corresponds to the case of fractured bone and assembled with the plate. It was observed that the efforts exerted on the healthy fibula are justified since the plate fulfills a similar function to carry the weight of the patient and even double this weight assuming a fall. Therefore, it is assumed that the plate fulfills without problem the function of supporting its own weight without deforming the device, even allowing it to remain stable until bone regeneration is achieved.

Keywords 3D printing · Bone · Stereolithographic models · Prosthesis implant

1.1 Introduction

This paper presents the result of simulations indicating a large workspace for the implant for type B ankle fracture rehabilitation which allows for use and implementation in rehabilitation therapies. Surgical procedures for treating chronic lateral

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ankle instability include direct anatomical repair, anatomical reconstruction with an autograft, and arthroscopic repair. Knowledge of specific implant designs is useful for developing an appropriate mechanical test protocol, for reconstruction involving an autograft which is another promising short-term option, although the longevity of this procedure remains unclear. Studies are needed not only on treatment for the fracture in the ankle where a type B fracture occurs, but also on reducing the risk of deterioration of the ankle joint.

1.2 Materials and Methods

Comparative analysis of the biomechanical performance of stabilization plates for ankle fracture type B was performed using the finite element method using segmentation and modeling techniques.

The type B fracture in the ankle is centered in a male patient of 90 kg of weight with a height of 1.80 m and with an age of 40 years in which the selection of plaque is made for the stabilization of said fracture. By this procedure, a model was obtained and subjected to stress tests (Fig. 1.1) [1–6].

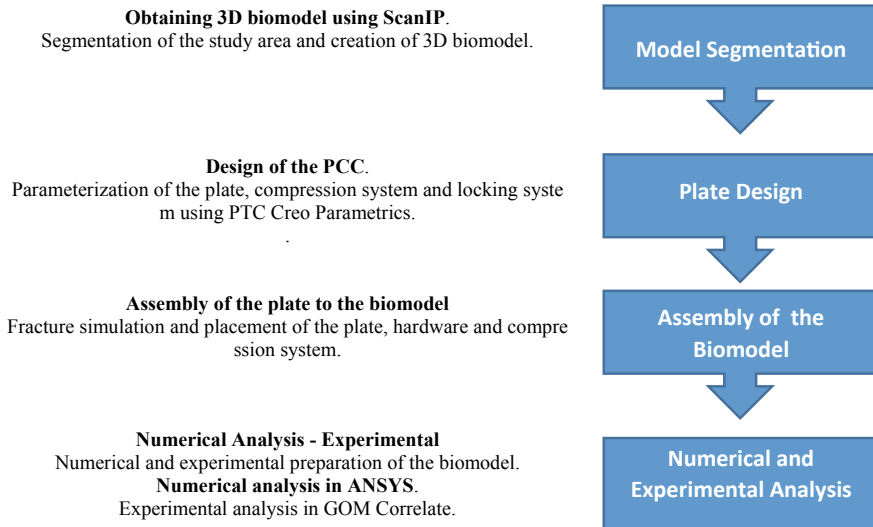


Fig. 1.1 Methodology for numerical–experimental analysis

1.2.1 DICOM Images

The patient was subjected to a computerized tomography of the pelvis without contrast. The scan was performed with a high resolution of 0.625. DICOM images, a universal medical imaging format, were obtained from the scanning service and analyzed in a MicroDicom scan viewer (open source) to account for the resolution and to verify that the entire sequence was present.

1.2.2 Segmentation

Once the images were registered, segmentation is the most important step in generating an accurate 3D CAD model from scan images. In general, segmentation means splitting into separate parts or segments. Model development requires several steps:

- Obtain patient scans
- Segmentation of domains of interest
- Surface mesh creation for pre-segmented domains
- Refining the surface mesh manually
- Create the volumetric mesh based on the refined segmented mesh

The first step is to get the proper scans, and this depends on the organs being analyzed. Scan types can be used for the development of skeletal models; however, if the soft tissue is also modeled, then MRI scans are used. Depending on the problem being analyzed, scans can be obtained from a healthy person or a person who has an injury (ankle fracture); the scans obtained correspond to the neutral position and without weight (Fig. 1.2).

1.2.3 3D Models

For the plate modeling, the extruded and combined tools were used within the ANSYS2020 R2[®] ACADEMIC interface, Space Claim[®] was used, and four cortical bolts, two locking bolts, and four spongy bolts were inserted (Fig. 1.3).

1.2.4 Contact Simulation

Analysis was performed in the ANSYS2021 R1[®] ACADEMIC software. Using finite elements reduces the number of prototypes to none for design and optimization since the entire process is computer-based. The static study of the numerical model, the

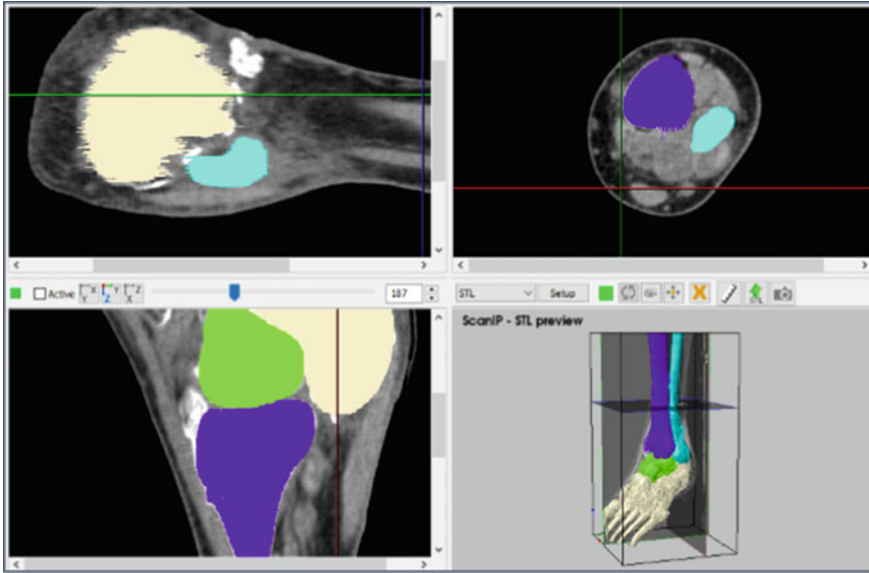


Fig. 1.2 Mask definition of each anatomical section to be reconstructed

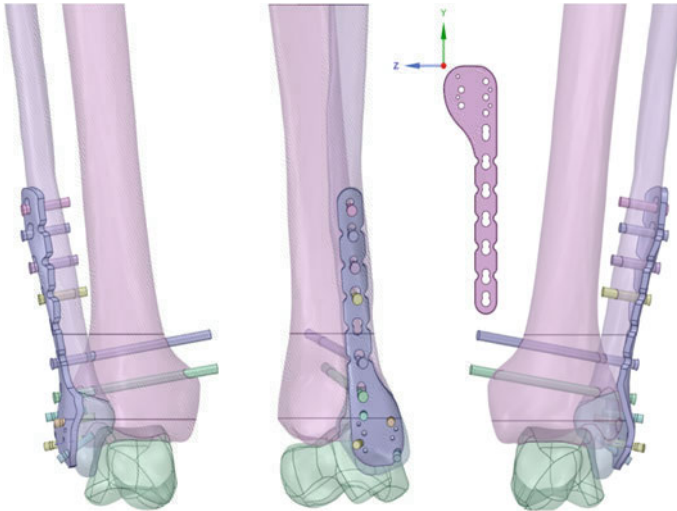


Fig. 1.3 Reconstructed model from segmentation after it was exported to an STL format

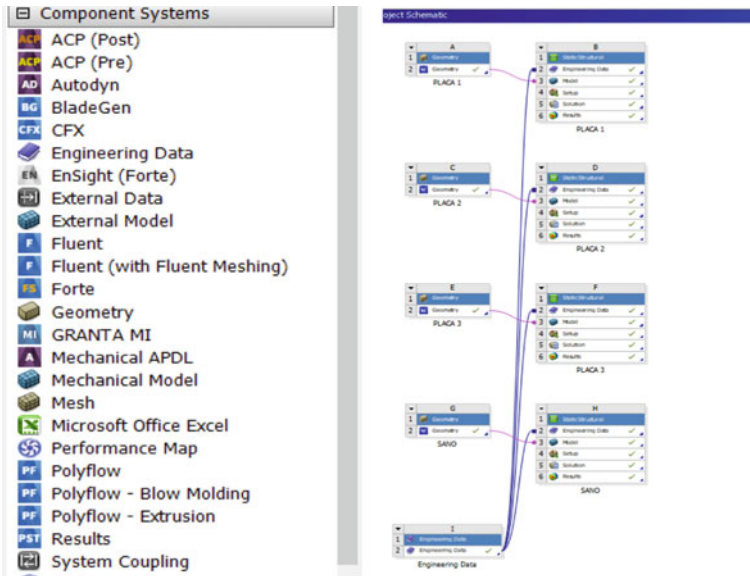


Fig. 1.4 Mechanical properties of medical grade Titanium ANSYS2020 R2® ACADEMIC

effect of muscle strength, the proper distribution of properties of bone materials on the distribution of tension in the ankle joint is studied separately [7–13].

All the elements were segmented, and the surface mesh of these elements was automatically generated and refined. Finally, the geometry command was used and a module was entered for each study section (Fig. 1.4).

The contacts displayed on the model surfaces were modeled as joined contacts. These are defined as Bonded, except for the contact of the fracture surface presented by the model. The latter is defined as "No Separation" (See Fig. 1.5). They were automatically detected by the computer program, assuming that contact must be defined at the place where the faces of the various materials overlap. Stress analysis was performed with von Mises failure criterion.

1.2.5 Meshing

The mesh in this study was an important part, because of the solving process of the analysis. The program solved the problem individually for each item, the result is provided for the whole body, and 15,856 elements containing 24,094 nodes are provided (Fig. 1.6).

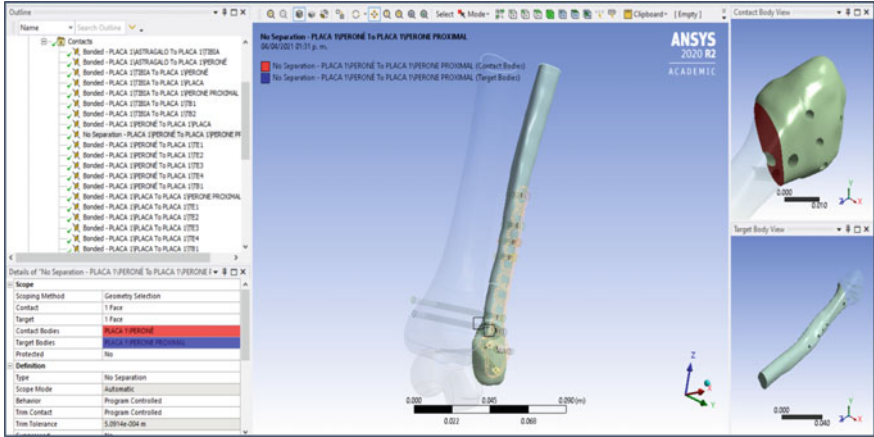
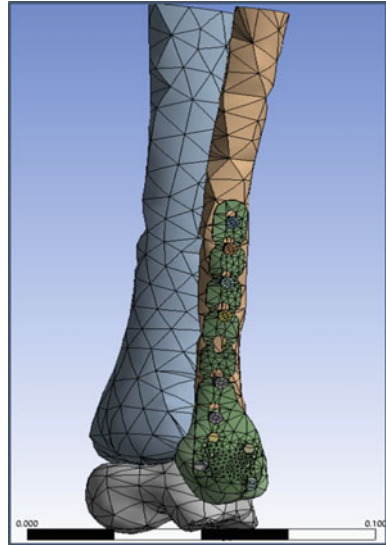


Fig. 1.5 Definition of contact for B-type fracture ANSYS2020 R2® ACADEMIC

Fig. 1.6 Mesh on the plate for type B fracture. ANSYS2020 R2® ACADEMIC



1.2.6 Loading Conditions

A vertical compression force of the average Mexican model of 90 kg was applied to the upper surface, where contact occurs for the application of the load, because, when walking in the medium support phase, a discharge of 3 times the total body weight is found, making it a load of 2648.7 N (Fig. 1.7).

Fig. 1.7 Load conditions for type B fracture. ANSYS2020 R2® ACADEMIC



1.2.7 Image Correlation

In digital image correlation (DIC), image analysis is used for the measurement of deformations. DIC is a technique of contactless measurement of complete field of deformation which used the GOM Correlate® software for the case study.

1.2.7.1 Cleaning

Clean the implant with 70% ethanol using absorbent paper to remove existing fat or dirt residues (Fig. 1.8).

1.2.8 Mottled with Stochastic Pattern

For this study, a pattern of specks was applied by mixing a small amount of black enameled paint; the enamel is harder to work and requires diluent in this solvent case. Apply a pattern of specks by mixing a small amount of black enamel paint, the enamel is more difficult to work and requires diluent in this case solvent, which makes it more durable. This may be preferable if it involves testing an intact type of implant and then performing the implantation before re-testing, where there is a risk

Fig. 1.8 Implant for ankle fracture type B before to be painted



of damaging the speck pattern. There are several methods for applying the speckling pattern, but the pneumatic gun technique is flexible and economical. The mixture is made in the reservoir of the system with which it is to be painted to prevent the solvent from volatilizing, holding the equipment perpendicular to the surface at a distance of 20 cm from the sample. (Fig. 1.9).

1.2.9 Tests on Samples Printed on PLA.

In the study, the models were fastened rigidly in the sample bracket on the mechanical tester platform to ensure that it does not move under load (Fig. 1.10). A minimum load of 90 kg is established on the device and the load is gradually increased to 270 kg as the average support stage gait cycle increases three times the body weight.

As shown in Fig. 1.10, the camera is placed to perform the digital image correlation in a rigid bar at an appropriate height to capture normal images of the implant surface. In the experiments, test mount images are used with an image size of 10×16 pixels (Fig. 1.11).

Fig. 1.9 Pattern of mottling on the implant plate

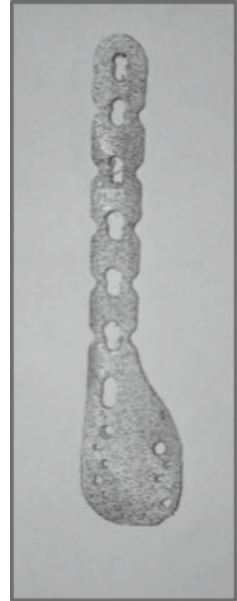


Fig. 1.10 Holding of the implant paste

1.3 Results

In relation to the results of numerical testing, under the von Mises criterion it was found that the maximum stress was 163.3 MPa and located in the diaphysis of the

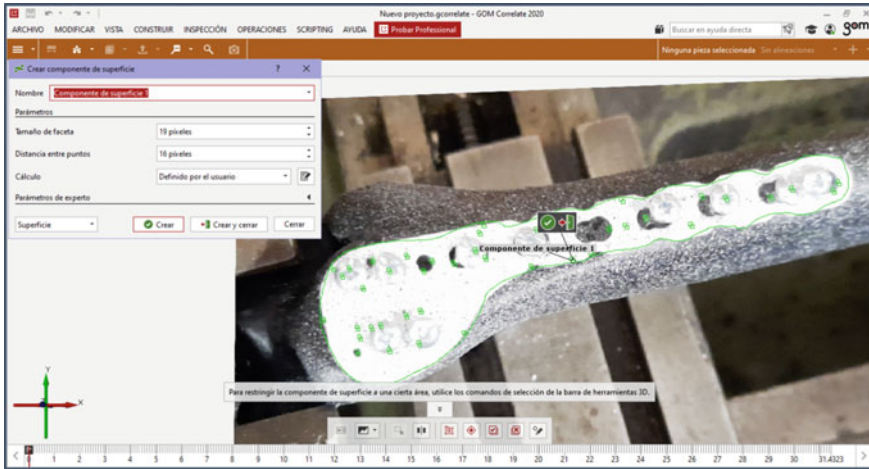


Fig. 1.11 Stochastic pattern on plate implant number one for GOM Correlate®

plate, and a minimum stress of 8.13 MPa was obtained. In the joint of the plate fracture, 10.991 MPa of stress was reported (Fig. 1.12). A displacement of the fibula toward lateral, natural anatomical movement was observed (Fig. 1.13).

The test was performed on a compact PLA-printed sample for plate number two loaded on a hydraulic testing machine (Fig. 1.14) and analyzed using a single camera DIC configuration in the GOM Correlate® software resulting in 0.02–0.027 of strain on the color spectrum scale.

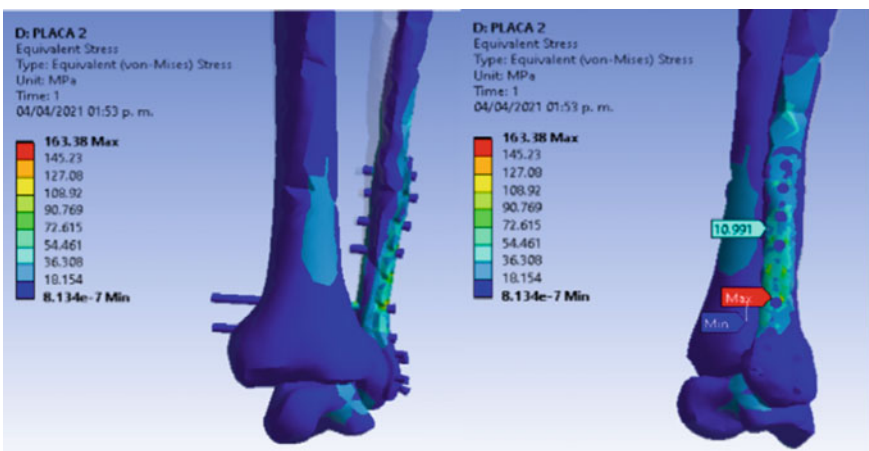


Fig. 1.12 von Mises stress results in plate implant using ANSYS2021 R1® ACADEMIC

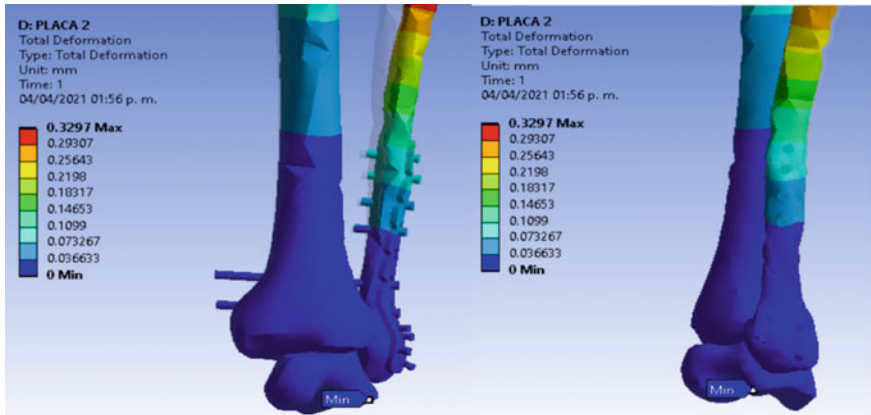


Fig. 1.13 Displacement results in the plate implant using ANSYS2020 R12® ACADEMIC

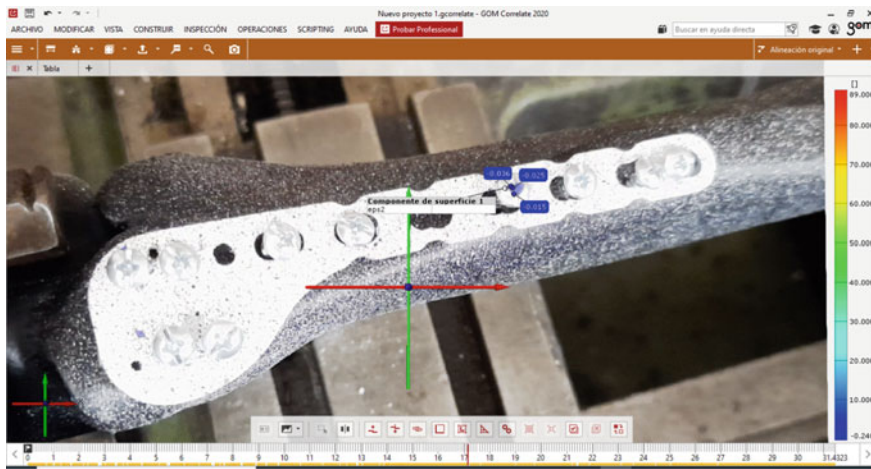


Fig. 1.14 Results for implant in GOM Correlate ®

1.4 Conclusions

The results showed that the stresses decreased near the surfaces where the type B fracture occurs after the insertion of the modeled implant intended for this study. The current results coincide in that the implant that settles on the distal fibula can support the forces in the ankle, which consequently can contribute to the optimal rehabilitation of the patient.

The analysis of the magnitude and distribution of the contact tensions in the ankle joint as a function of the load condition and ankle position is important to understand the fracture type B, and the understanding of the load distribution is the basis for the

biomechanics of the ankle joint, since changes in the biomechanics of the ankle lead to an altered load transmission through the ankle joint, which in turn can predispose the joint to real conditions of study.

The main limitations of this study are the load conditions considered in the model. This selected load case corresponds to discrete support phase posture times. In fact, it is expected more complex load conditions—there are not enough computational resources to consider the entire load range of the support phase of the walk. There is no information in the literature about muscular forces, so they were not included in the present work.

By completing all the digital imaging correlation, data collection, data analysis, and data presentation tests, the final results can be considered and interpreted from some biomechanical considerations. The digital imaging correlation test data is useful to be compared with a finite element model, specifically with the implants for type B fracture, because the strain and failure can be decreased with the inclusion of this implant. Medics and surgeons can evaluate the mechanical behavior and advantages from this type of implant and loading conditions. The medical criterion is very important for this numerical and experimental testing [14].

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