MECHANICAL ANALYSIS OF SCANDINAVIAN TOTAL ANKLE REPLACEMENT PROSTHESES THROUGH FINITE ELEMENT

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Abstract - The paper presents the results of the processing of information obtained by studying the Scandinavian Total Ankle Prosthesis (S.T.A.R.) second generation and third generation. Knowing the geometric and mechanical characteristics, evaluating the nodal forces (forces and couples) caused by the distributed loads along the endoprostheses, this study was realized considering that a finite element model of the ankle joint could be useful to provide a perspective on the mechanisms the effects of treatment, and the role of mechanical factors in degenerative conditions. Preparing such a model involved many geometric simplifications and the introduction of material properties.

Keywords: Total ankle arthroplasty, Endoprosthesis, reconstruction 3D, Finite element method, The S.T.A.R. prosthesis.

1. Introduction

Normal operation of the ankle is necessary for walking easily and effortlessly. Muscles, tendons and ligaments that support the ankle joint work together to propel the body. The unique ankle joint is very stable to support the weight of 1.5 times the person goes and eight times the person running.

2. Scandinavian Total Ankle Replacement Endoprosthesis (S.T.A.R.) of the Second Generation and Third Generation

Scandinavian Total Ankle Replacement endoprosthesis (STAR) of the second generation,

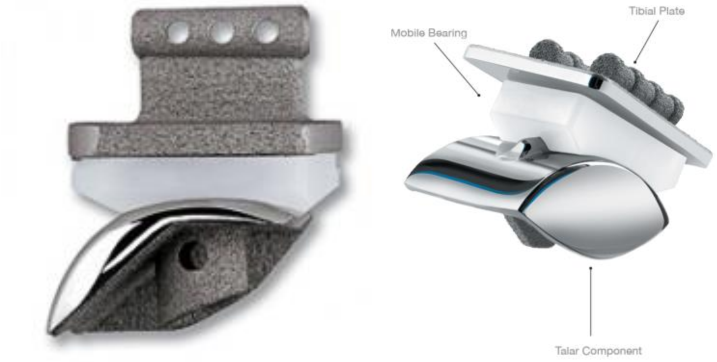
Figure 1 [1] is made up of two metal components coated with hydroxyapatite, and 1986 in the tibial side of the prosthesis STAR polyethylene component was included. This change was made to minimize the stress of rotation to interface the implant-bone, showing a prosthesis cylindrical three components [2].

Metal components are made from alloys of cobalt-chromium and coated with a layer of hydroxyapatite or phosphate calcium and titanium.

Polyethylene component ranges in thickness from 6 to 10 mm. Surfaces of metal components have been increased, the decrease in mean pressure and making local contact during walking [3].

Other prosthesis under study Scandinavian Total Ankle Replacement is endoprosthesis (STAR) third generation, Figure 1b [4].

The first draft of the prosthesis STAR ™ was developed by Dr. Kofoed in 1978 and the first prosthesis was implanted in 1981 [5].



(a) (b)

Figure 1: Scandinavian Total Ankle Replacement 1, the second generation: (a) generation of the second [1], (b) of the third generation [4]

The current draft of the STAR prosthesis is a prosthesis congruent cylindrical three components. Integrating initial bone prosthesis is provided by one leg on the talar and tibial two fins on the cylinder.

Ankle prosthesis models of modern third generation do not use fixing with cement.

The use of the implant improved metal surfaces and various approaches for determining the tibia and the talus, such as screws, long rods or short rods to secure cylindrical or rectangular bar tibia and the talus for securing and sometimes for fixing the tibia [4].

Endoprosthesis has a movable, two fixed parts and slipping, tilting and rotational movements of the ankle.

The endoprosthesis STAR ™ is composed of three parts: component talar that cover the talus or the bone of the lower ankle joint, plate tibial covering the lower part of the bone tibia and the movable support to move between the metallic parts while the ankle is moving, made of UHMWPE [6].

3. STAR and STAR ™ Prosthesis Design Using Autodesk Inventor Design Software

STAR ™ and STAR prosthesis having a structural static behavior of complex calculations impossible to evaluate the resistance classes.

Evaluation of the stress, strain and contact elements designed to perform the static analysis of the structural assembly.

3.1 Geometric Modeling of the Prostheses

First step was to design prostheses STAR and STARTM based on information provided by companies DePuy Orthopedics, Inc. [7] Small Bone Innovations, Inc. [8], respectively. For the design of the device used design software Autodesk Inventor [9] [10].

In Figure 2 we can see shaping concept STAR prosthesis (left) and prosthesis STAR ™ (right).

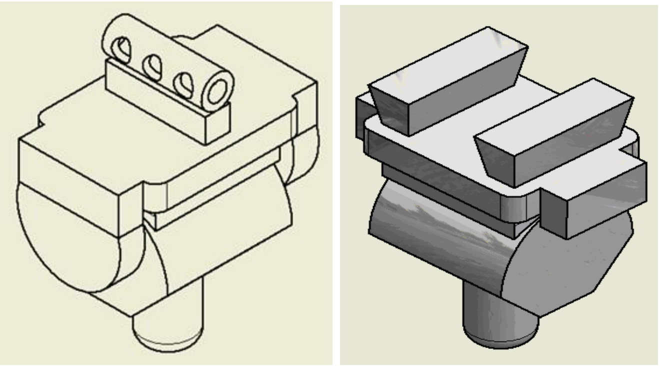


Figure 2: The endoprosthesis STAR (left) and the prosthesis STAR ™ (right)

3.2. Generating Discretization

To analyze the structure of the two models were studied endoprostheses elements which form them, all of which are connected by nodes. Stress conditions were applied to these elements and nodes.

Ankle state model generation for the two nodes 9255 and 5395 resulted elements, and for STAR Ankle model of a third generation nodes 7856 and 4747 resulted elements.

3.3 Declaring materials involved in the analysis

Assigning material was made for each of the components assemblies are biocompatible materials shown in Table 1:

Table 1. Material properties defined in the three models under study: S.T.A.R. and S.T.A.R.™

Models	Component	Material
S.T.A.R.	Plate and Screws	Ti
S.T.A.R.	Tibial component	Ti
S.T.A.R.	Polyethylene	UHMWPE
S.T.A.R.	Talar component	Co-Cr
S.T.A.R.^{TM}	Tibial component	Co-Cr-Mo
S.T.A.R.^{TM}	Polyethylene	UHMWPE
S.T.A.R.^{TM}	Talar component	Co-Cr-Mo

3.4. Defining tasks

To achieve motion simulation mechanism von Mises stress and displacement cinematic elements, used special software library Inventor Stress Analysis [10].

In Figure 3 we can see the selected area and its sense of force, indicated by yellow arrow.

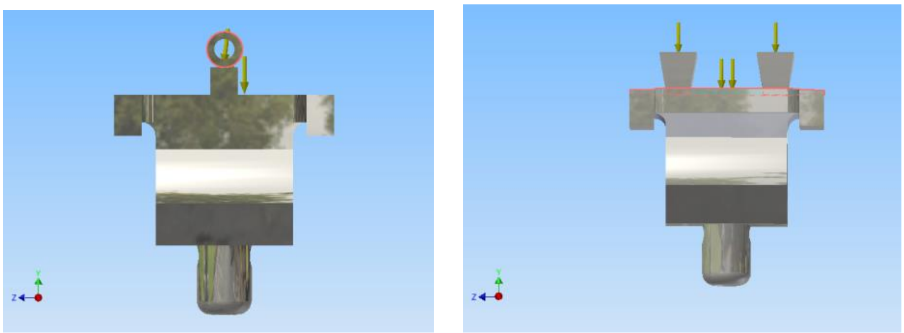


Figure 3: Select faces: STAR prosthesis (left) and endoprosthesis STAR ™ (right)

In Figure 4 It was defined by the contact surface behaviour and interactions were considered and rigid surface between the cartilage and bone, between the bone and the interosseous membrane between the bone and the prosthetic components screw-plate-bone. Both screws were also considered and rigid plate.

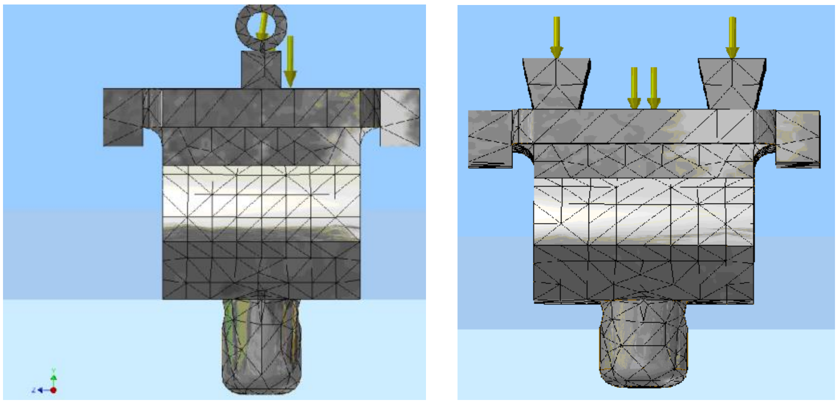


Figure 4: Declare contacts between elements:
STAR prosthesis (left) and endoprosthesis STAR ™ (right)

3.5 Charging conditions used in this study

They were applied pressure forces and axial movements. Figure 5 shows the movement in some areas in both models under study.

To achieve the simulation was performed finite element mesh models.

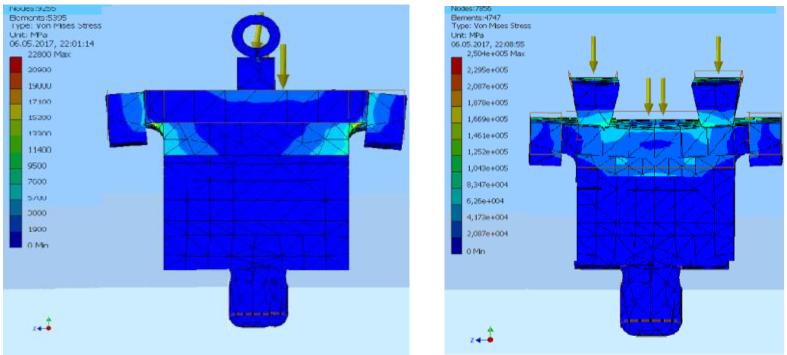


Figure 5: Application and pressure for moving tasks:
STAR prosthesis (left) and the prosthesis STAR ™ (right)

In Figure 6 can be seen as resulting tensions and movements of the arms of the two models endoprosthesis after application of axial forces to values of 700 N, 1200N and 1600N.

The main limitations of this study are considered models load conditions.

For each model were applied to three different cases of static load.

These selected load cases correspond to times of position driving phase and are considered representative of the range of tasks developed during phase position.

However, the reality is more complex loading conditions.

In fact, there is sufficient computational resources to consider the whole range of loads of phase driving position.

Moreover, there is no information in the literature about muscle forces, so were not included in this paper

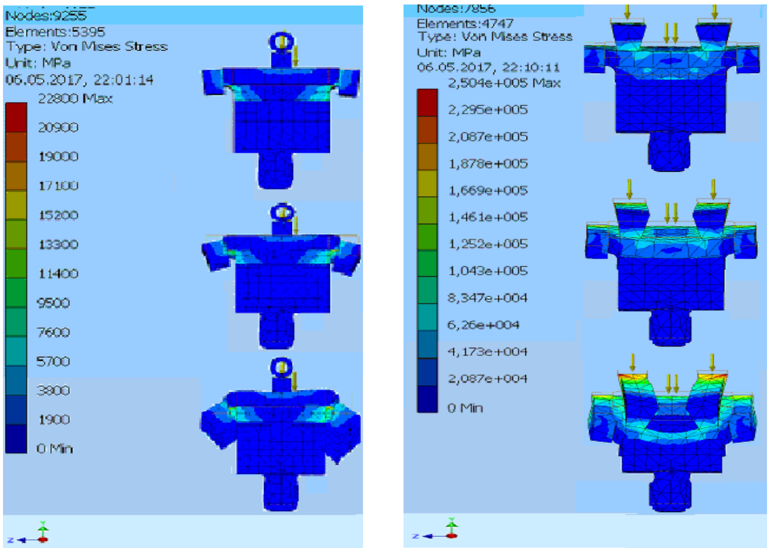


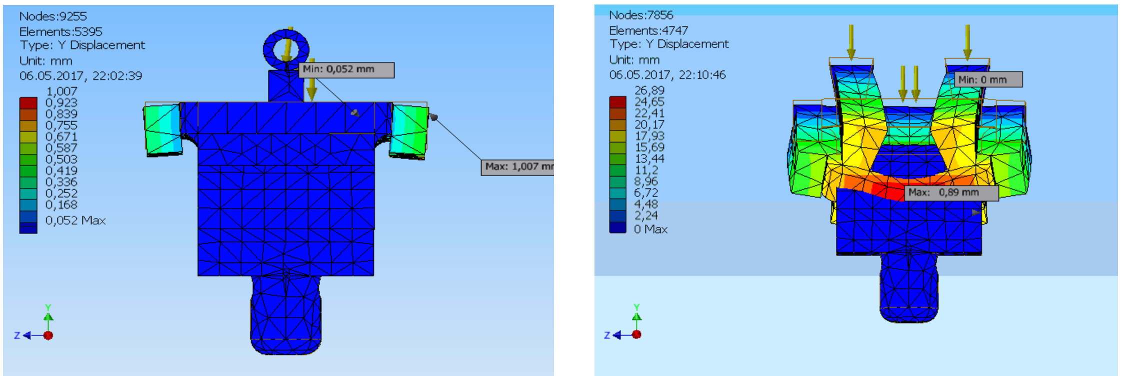
Figure 6: The application of axial forces to values of 700 N, 1200N and 1600N: STAR prosthesis (left) and the prosthesis STAR ™ (right)

Wider shape design new talar component of the prosthesis STAR ™ to the trailing edge and the contact surface has led to a decrease in maximum contact effort of 17.59 MPa (the old model) to 5.32 MPa (in new design).

Table 2 shows the results von Mises stress in the two prostheses.

Table 2. Tensions von Mises structure prosthesis

Name	S.T.A.R.		S.T.A.R.™	
	Minimum	Maximum	Minimum	Maximum
Von Mises Stress	0 MPa	17.59 MPa	0 MPa	5.32 MPa



(a) (b)

Figure 7: Displacement values for the axial forces of 700 N: STAR prosthesis (a) and the prosthesis STAR ™ (b)

Table 3 shows the results under the action of axial displacement of 700 N for both STAR prosthesis, and the prosthesis STAR ™.

Table 3. The results under the action of axial displacement of 700 N

Name	S.T.A.R.		S.T.A.R.™	
	Minimum	Maximum	Minimum	Maximum
Y Displacement	-1,00666 mm	0,0524609 mm	-0,8886 mm	0,009853 mm

4. Conclusions

In this study, our objective is to investigate how contact during charging ankle for two prostheses STAR and STAR ™.

The study has developed a method for the application of axial loads on the human ankle weight similar conditions.

It was considered natural ankle joint geometry. It was created a three-dimensional model of the contact and boundary conditions were applied based on the image to investigate the distribution of stresses during loading.

Contact stress distribution was evaluated in polyethylene component.

They compared the model predictions with known load conditions and image deformation.

The results indicate that STAR ™ model has better performance than its predecessor, STAR also observed in both hearing problem charging marginal.

A method of comparing model predictions with real behavior under controlled conditions may make it easier choice ankle prosthesis model before performing the operation.

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