ORIGINAL ARTICLES

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Finite element analysis of a modified short hip endoprosthesis

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Abstract: *A finite element simulation of the mechanical static features for a modified short hip endoprosthesis was performed. The corkscrew-like femoral stem was modified introducing more turns of the thread. By such an approach it is expected that for some cases the mechanical fixation of the prosthesis to the bone will be improved or the use of the cement for bonding is not necessary. Our scenario was estimated for titanium and stainless steel, and both materials show good safety factors. Mechanical stress is expected to be distributed more uniform in the bone for the new design with more turns of thread.*

Keywords: *modified short hip endoprosthesis; design; finite element analysis; titanium; stainless steel*

INTRODUCTION

The increase in the average life expectancy rose the age at which different surgical interventions are performed. For example, the total replacement of the hip is made on a typical patient of 60-80 years old, and often patients are older, in some cases even over 100 years old. The primary hip intervention can be followed by several revision surgeries [1,2,3]. This is a reason for designing modular endoprosthesis, where damaged parts can be easily replaced.

A short femoral stem is recommended for patients where the femoral bone allows a minimal resection, and the bone structure has enough mechanical resistance to support the stress induced by implant [4]. A positive aspect of our design consists in screwing the implant into the bone, avoiding its hammering [5,6] that has a high risk of femoral neck fracturing. The prosthesis has a cylindrical metallic body, with an exterior thread, continued with a truncated sleeve, and ended with a junction neck (Figure 1). Inside of the implant there is a hexagonal hole for the insertion of a torque screwdriver (not shown). The distribution holes are built-in and they are intended to be used to spread the cement for fixation after the stem is screwed in the bone.

In this work a modified design is proposed. Namely, more turns (7 instead of 3) [7] of the screw-component of the endoprosthesis are considered. Expectations are to obtain an improved implant-bone fixation and a more uniform distribution of the forces that will allow a longer lifetime with less revision surgeries: it is well known that after about 10-15 years the prosthesis loosens and a replacement may

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be required [8]. For certain cases it is thought that our improved design may also provide a cement-free fixation. Finite-element analysis is used to estimate mechanical features of the prosthesis with the modified design. Two materials, titanium and stainless steel are considered.

MATERIALS AND METHODS

1. CAD design and materials properties

The endoprosthesis was designed [9] in Inventor Professional 2016, and the materials properties were assigned from the software database.

The proposed materials for the endoprosthesis are titanium and stainless steel (Table 1). Materials are considered isotropic and linearly elastic.

2. Mesh settings

All the settings are detailed in [6]. The total number of the resulted elements was 1,694, and the total number of the nodes was 3,287.

Table 1. Mechanical properties of materials used in simulation.

Material	Density [g/cm^3]	Young's Modulus [GPa]	Poisson's ratio	Shear Modulus [GPa]	Yield strength [MPa]	Tensile strength [MPa]
Titanium	4.51	102.81	0.36	44	275.6	344.5
Stainless Steel	8.00	193.00	0.30	86	250.0	540.0

3. Boundary and loading conditions

The endoprosthesis, either the initial or the modified design, is considered fixed on its stem, thread, and under the supporting disk for the scenario when using cement (Figure 1.a, blue region). For the cementless approach only the thread and the part under supporting disk are considered fixed. (Figure 1.b, blue region).

A load of 6000 N magnitude is analyzed, as the most unfavorable case [7]. Both scenarios are studied without the implant/cement/bone interactions.

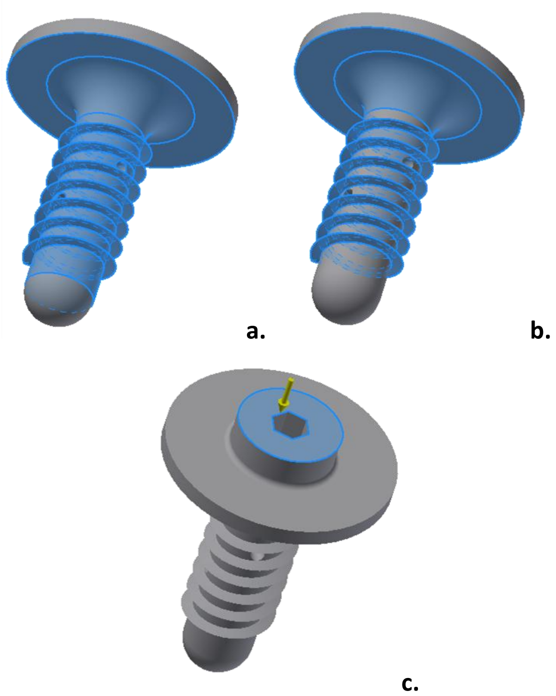
A static compression load is distributed on the upper surface of the disk (Figure 1.c, blue region denoted with an arrow). The safety factor is based on the yield strength.

RESULTS AND DISCUSSION

The simulation results are shown in Table 2 and Figures 3, 4 and 5. The differences between the initial and modified designs are not significant, for selected materials, titanium and stainless steel.

A longer thread suits better for a cementless fixation (Figure 1.b), due to the larger contact area. For the stainless steel, the analysis is shown in Figure 5. The static finite element analysis shows no significant differences when compared to the "cemented" scenario.

Figure 1. Fixed constrained areas of the modified short femoral endoprosthesis: (a) for "cemented", and (b) "cementless" scenarios. (c) Selected area for force distribution.

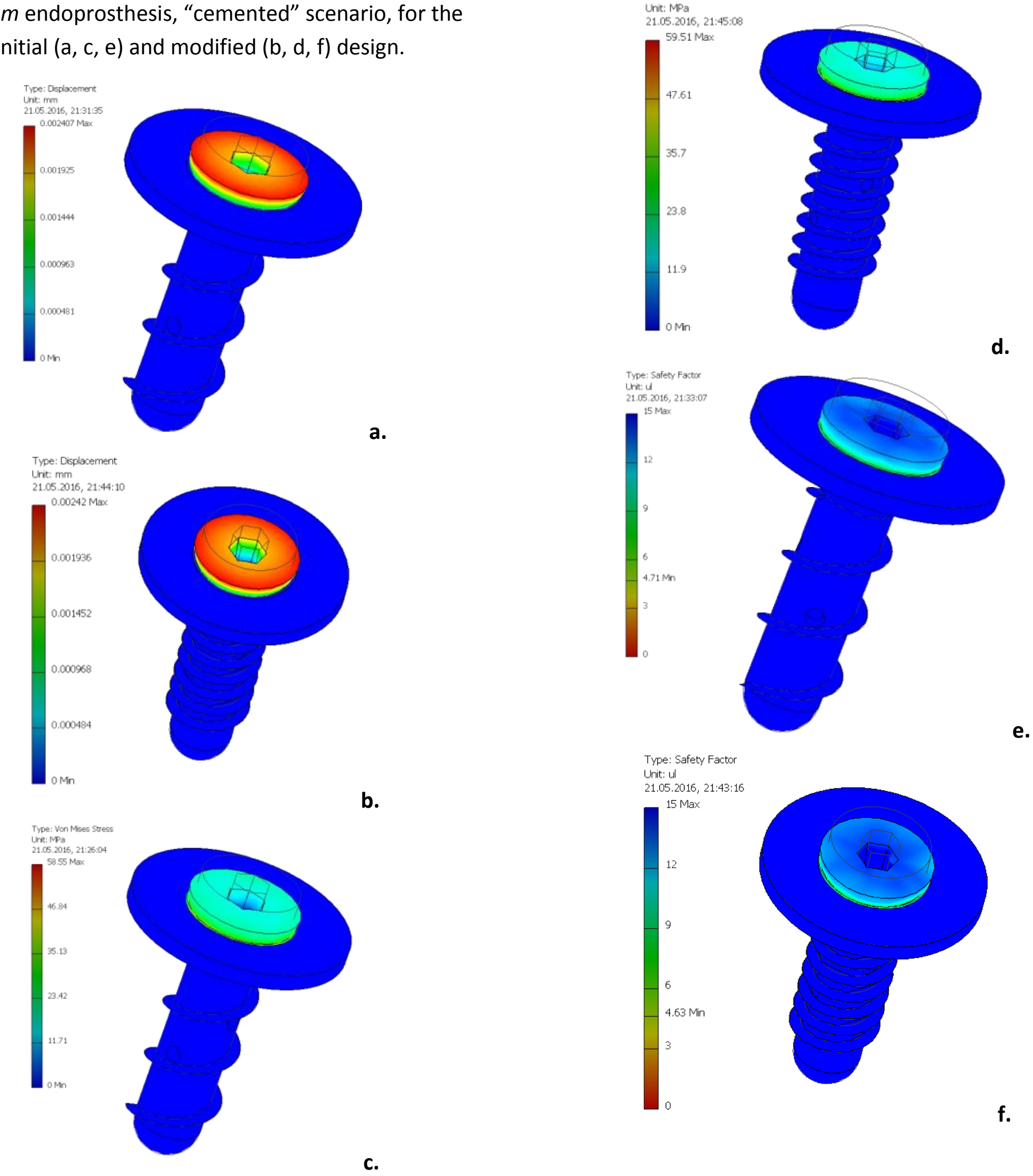


This approach confirms that the new design does not affect the mechanical behavior of the endoprosthesis. A longer thread is also expected to provide a better stress distribution in the femoral neck and further studies are required.

Table 2. Maximum displacements, maximum Von Mises Stress, and the minimum safety factor for a 6000 N load and different threads.

Materials	Displacement [max, µm]		Von Mises Stress [max, MPa]		Safety factor [min, ul]	
	initial	modified	initial	modified	initial	modified
Titanium	2.407	2.42	58.55	59.51	4.71	4.63
Stainless Steel	1.319	1.326	59.68	59.86	4.19	4.18

Figure 3. Displacement magnitude (a, b), Von Mises Stress distribution (c, d), and overall safety factor (e, f) for *titanium* endoprosthesis, “cemented” scenario, for the initial (a, c, e) and modified (b, d, f) design.



a.

b.

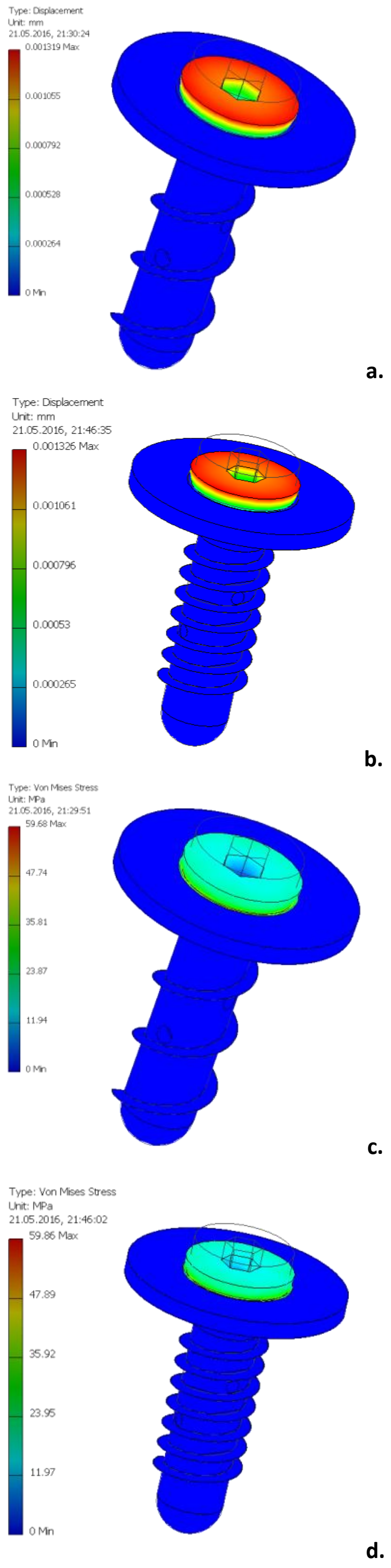
c.

d.

e.

f.

Figure 4. Displacement magnitude (a, b), Von Mises Stress distribution (c, d), and overall safety factor (e, f) for *stainless steel* endoprosthesis, “cemented” scenario, for the initial (a, c, e) and modified (b, d, f) design.



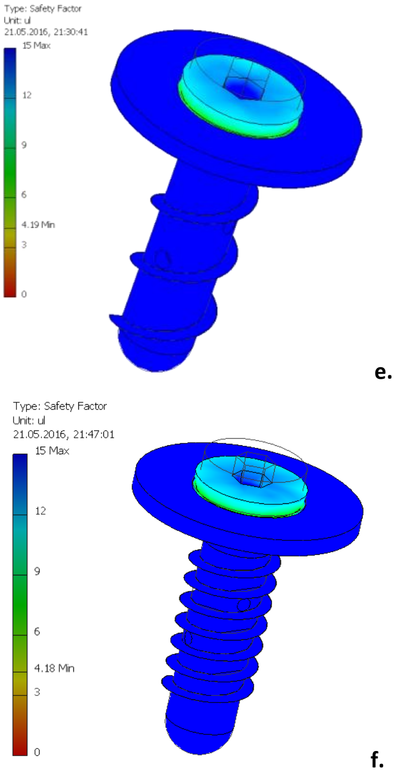
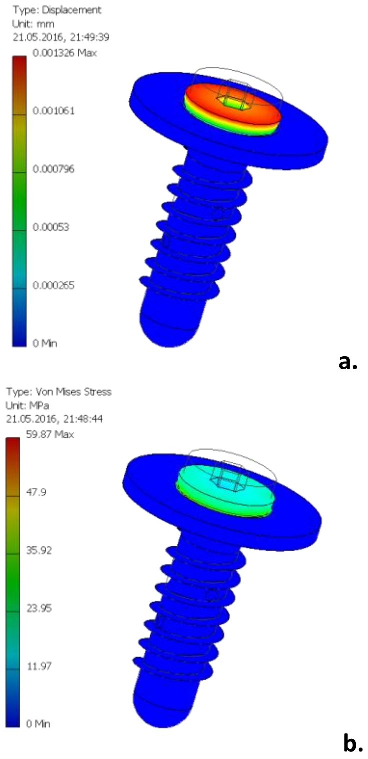
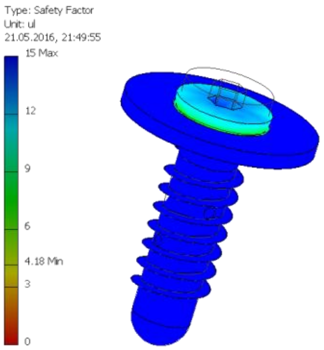


Figure 5. Displacement magnitude (a), Von Mises Stress distribution (b), and overall safety factor (c) for the *stainless steel* modified endoprosthesis. A “cementless” scenario (6000 N load) is considered.





c.

CONCLUSIONS

A modified short hip endoprosthesis design is proposed as a better solution than the previous one, where a fixation using cement is considered. The new simple design consists in a longer thread that increases the friction force between endoprosthesis and bone by increasing the contact surface. The finite element analysis shows that the modified design does not affect the mechanical behavior. This design may allow, in some cases, a cementless fixation. Further tests are necessary to confirm our results.

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