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NUMERICAL SIMULATION OF STAPLES FOR EPIPHYSIODESIS

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Abstract: *Bone staples are used for epiphysiodesis, which is orthopedic surgery correcting bone deformities, eg. varus or valgus deformity and length discrepancy. Stresses and displacements caused by interaction between staples and tibia are calculated via the finite element method. Determined values are used for bone staples assessment and clinical applications for treatment of patients.*

Keywords: Biomechanics, Orthopedics, Epiphysiodesis, FEM, Staple.

1. Introduction

Epiphyseal stapling is a method of bone growth control using metal staples implanted into a specific part of children's bone to temporarily prevent its growth. The method was introduced by Walter Blount (Blount, 1949) and since then it became a common procedure of correcting mainly angular deformities (genu varum or genu valgum) of the knee in children. Growth of children or adolescent bone is provided mainly by physis, i.e. a cartilage structure near joints. Using the staple, we can restrain the physis either on both sides when correcting limb length discrepancy (i.e. 'epiphyseodesis') or on one side only when correcting angular deformities (i.e. 'hemiepiphyseodesis'). Unlike the method of permanent epiphyseodesis (Phemister, 1933), the epiphyseal stapling does not destroy the physis and therefore makes possible to restore the growth when the optimal correction is achieved. Although recently, the tension band technique introduced by Peter M. Stevens (Stevens, 2007), using a non-locking plate and two screws almost in the same position like staples, has slowly became a preferable alternative to stapling. Blount's original method still remains an effective means to treat lower limb deformities in adolescents.

Fig. 1: Long radiogram of preoperative genu valgum and consecutive correction with staple.

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Apart from accurate diagnosis confirmed by radiogram of whole limb (Fig. 1), good timing of treatment is very important. The operational procedure includes short longitudinal incision through soft tissues over the physis and implantation of staple extraperiosteally with special instrument and under radiographic control (Fig. 2). The staple must bridge the physis but must not penetrate it to prevent its impairment (Fig. 3). The staples should not be restricting the physis longer than 2 years to prevent its permanent growth cessation. Other complications during treatment can occur such as damaging the physis by imprecise staple implantation, mechanical failure of the staple (banding, rarely break) or staple migration. The last one is also the most often complication and disadvantage compared with tension band technique.

Fig. 2: Implantation of staples.

Fig. 3: Position of staples bridging the physis.

2. Computational Model of Staples in Tibia

To determine the behavior of bone staples used during treatment of Epiphysiodesis, a computer model of proximal part of tibia was created. This model was then split in the place of epiphyseal disk for further simulation of bone growth, see Fig. 4a. For this determination a set of two bone staples was chosen, for example see Fig. 4b. For more realistic approach (simulating staple migration), the contacts between bone staples and bone were set as frictional, with friction coefficient 0.2 acquired via educated guess. The reasoning behind this contact is the possibility of staple migration as mentioned before also due to staples flat surface. Provided models of bone staples from MEDIN a.s, were put into place as in real treatment, to slow the growth of epiphyseal disk see Fig. 4c.

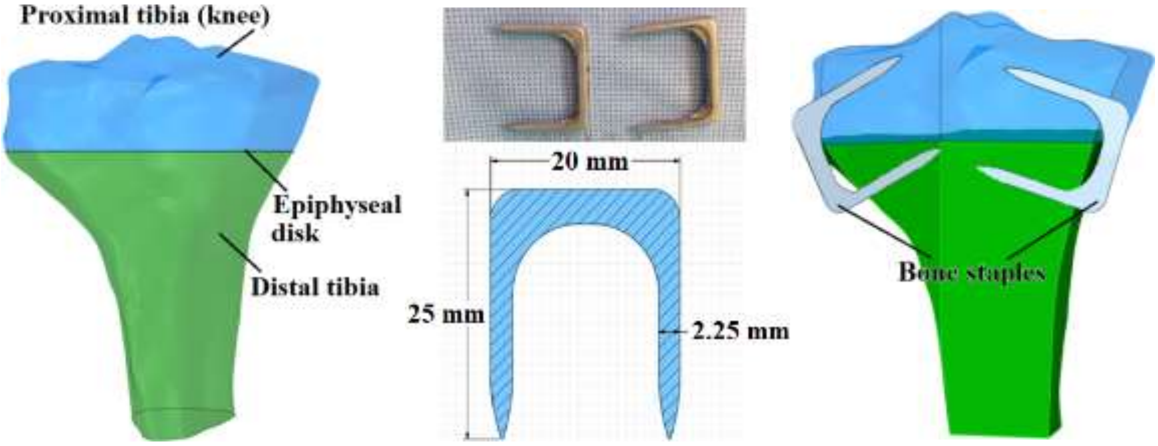


Fig. 4: a) Model of split tibia; b) Bone staples; c) Final model of split tibia with staples.

Material models of both bone and steel are assumed homogenous and isotropic, see Tab. 1 and (Drápala, 2018; Hlinka, 2016 and Losertová, 2016). The emphasis is put on bone staples. Hence, there is no need to divide tibia into cortical and spongiosal part (i.e. simplification).

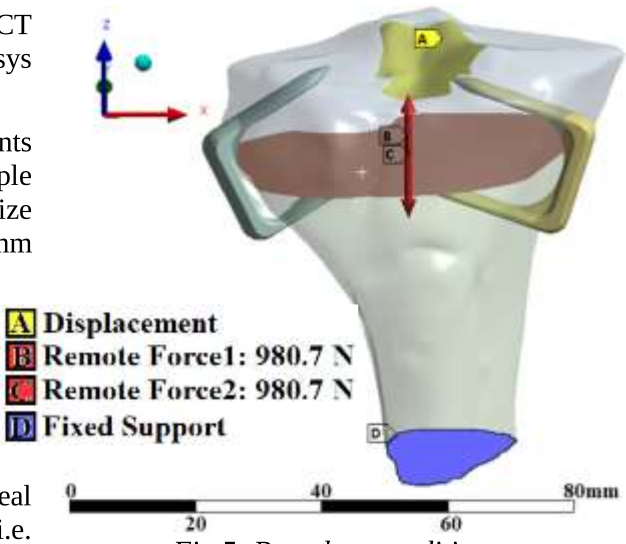
Tab. 1: Mechanical properties of bone and steel.

Material	Young's modulus [GPa]	Poisson's ration [1]	Yield stress [MPa]
Cortical Bone	0.161	0.3	–
Stainless steel 1.4441	183	0.33	690

3. Stress-Deformation Analysis

Anatomical CAD model of tibia (acquired by 3D CT scan) with staples was then imported into Ansys Workbench 2019 R3 sw for further computations.

Bone model was meshed by quadratic tetra elements with average element size of 5 mm. Bone staple models were meshed with average element size of 1 mm. Element size was locally reduced to 0.5 mm in places with stress concentration.



Fi. 5: Boundary conditions.

The bone growth is simulated by internal tensile stress in bone acting as magnification (growth) of epiphyseal disc. Used boundary conditions are shown in Figure 5. Two forces "B" and "C" of value 980.7 N ≈ 100 kg, which may occur after growth over time, due to the expansion of epiphyseal disc, were used as complex tensile forces (i.e. overloading) for simulation of bone growth. Displacement "A" acts as a weak simulation of a knee (for stabilization of numerical solution), therefore, in this case only allowing vertical movement in the direction Z of growth. Fixed support "D" acts as a definition of position of bone in space, not allowing any movement.

4. Results

From the results of stress-deformation analysis can be determined that the maximum stress occurs in sections of staples with radius and narrowed cross section, see Fig. 6. The maximum stress is where the singularity occurs and therefore the evaluated maximum stress is taken from place identified as "DETAIL".

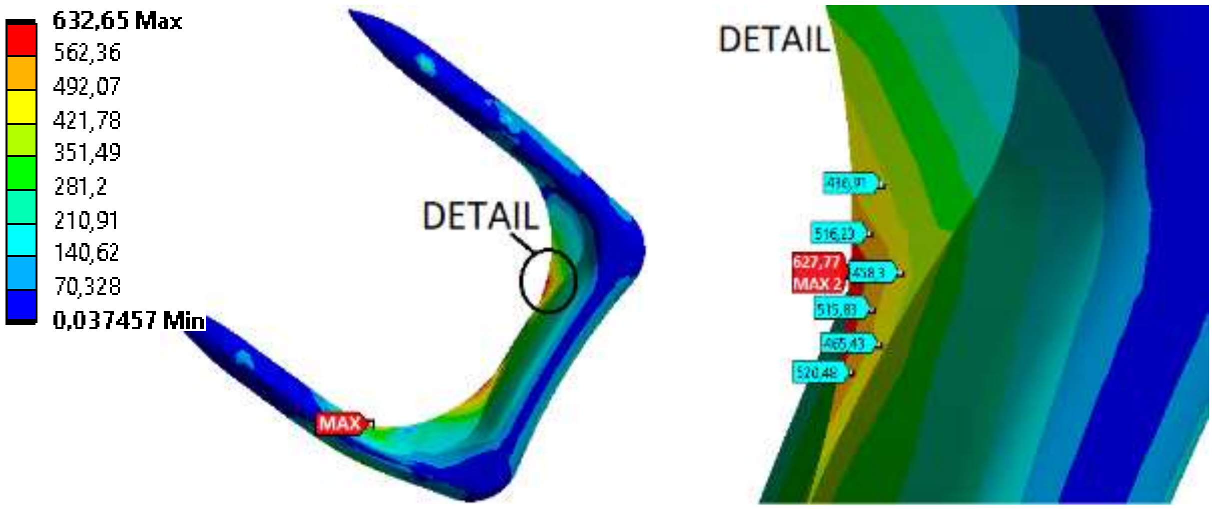


Fig. 6: Equivalent von Mises stress distribution and maximum stress in staple [MPa] (remote tensile forces 980.7 N).

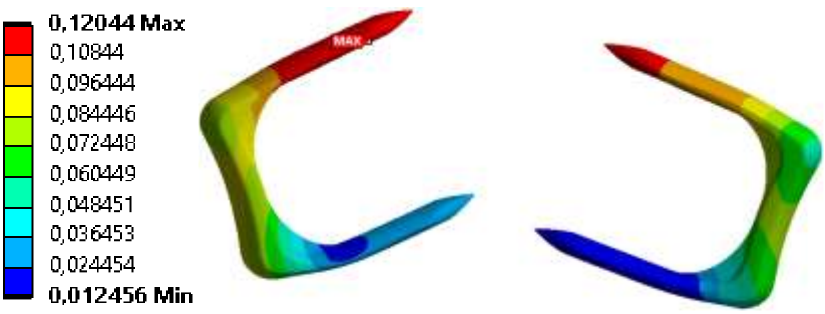


Fig. 7: Total displacement of bone staples [mm] (remote tensile forces 980.7 N).

Maximum displacement occurs on parts of bone staples which are located inside proximal part of tibia, due to growth of bone, which pushes this part upwards, see Fig. 7.

Bone was also analyzed and found sufficiently safe, because the bone tissue is practically intact around the bone staples. Therefore, there is no risk of any relevant mechanical damage (i.e. no fracture occurs).

5. Conclusions

In orthopedics, the bone staples are used to correct limb length discrepancy by implanting them into proper parts of tibia or other suitable bones. Evaluation of stresses and displacements in staples were done by the finite element analysis (ANSYS WORKBENCH 2019 R3 sw). Used models of staples were provided by MEDIN a.s. Bone growth was performed via overloading by estimated axial tensile force $980.7\ \mathrm{N} \approx 100$ kg acting in epiphyseal disk.

Bone staples are made from medical grade stainless steel 1.4441. Minimum yield strength of this steel is 690 MPa. The calculated maximum equivalent von Mises stress in staple is 627.77 MPa. This stress is smaller than minimum yield stress even in the place of singularity in FEM model (i.e. safe state, recommended for medical treatment). Calculated total maximum deformation of staple is 0.125 mm. Hence, because calculations were done for overloading, the staples and their applications are safe and suitable for medical applications.

Results may differ from person to person (anthropometry) and huge part of variance can be caused by staple placement.

For future endeavors, a heterogenous material (considering spongy bone and different mechanical properties in different parts of the bone) can be used and to verify these results, also an experiment should be done.

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