FINITE ELEMENT ANALYSIS OF HEMIPELVIC CUSTOM-MADE RECONSTRUCTIONS IN THE LONG-TERM FOLLOW-UP

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Introduction

Pelvis reconstruction after primary bone tumour resection surgery is still very challenging today. Custom-made 3D printed pelvic prosthesis are increasingly used to restore patient anatomy and physiological load transmission. They significantly shortened surgery, and are clinically successful in the short-term, but their long-term biomechanical risk, and consequent possible need of structural customization of the design have not been studied yet.

Our study belongs to a larger project that studied the mechanical behaviour of 3D printed custom-made hemipelvis. Results on six patients analysed at 32 ± 18 months of follow-up through motion analysis and musculoskeletal models reported a good functional recovery [1] but a concurrent asymmetry of the internal loads between limbs [2].

To evaluate the prosthesis safety and the risk of bone fracture or resorption in the long term, we built subject-specific finite element (FE) models, and we quantitatively estimated prosthesis stress and bone strain distribution in the force peak instants of walking (most frequent, monopodalic task) and squat (demanding bipodalic task).

Methods

FE models of six patients (2 females and 4 males, age=31 ± 7 yrs, BMI 22.6 ± 2.9 kg/m^2, follow-up time=32 ± 18 months) were built starting from CT-images [3]. A 10-node tetrahedral mesh was generated to model bone, prosthesis, and cartilage components, whereas tensile-only trusses were used for ligaments (Figure 1).

Bone was considered isotropic and inhomogeneous, and properties were mapped from CT-data using validated relationships [4]. Material properties for prosthesis [5], cartilage [6] and ligaments [7] were taken from the literature.

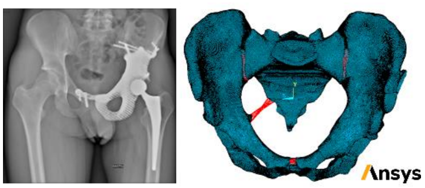

Figure 1: The RX of patient #3 and the corresponding FE model derived from CT-data.

Loads were extracted from personalized musculoskeletal models, considering hip and muscles (19 muscles per side) forces, and distributed over anatomical attachment areas. Three patients were classified as symmetric, and three as asymmetric according to peak values of hip reaction forces in the intact and operated hemipelvis during walking.

Results were analysed in terms of Von Mises stress in the prosthesis and principal strain in the bone.

Results

Von Mises stresses in the prosthesis body were < 50 MPa for both walking and squat simulations.

Linkage elements (screws and screwed flaps) showed higher stresses, which were below the usually assumed fatigue limit for titanium alloys (400 MPa) but revealed an unwanted bending condition in sacroiliac screws, and possible concerns for sizing of pubic flaps, where stress was maximum at 300 MPa.

The distribution of strain in both motor tasks did not overcome 3000 μstrain, regarded as a physiological limit [8]. Corresponding highly strained areas (e.g., greater sciatic notch) of intact and operated side showed similar values in symmetric cases, while the operated hemipelvis was strained 50-70% less than the intact one in asymmetric cases, pointing to a possible risk of bone resorption over time.

Discussion

FE results indicated that the prosthesis body, currently personalized upon anatomy, is safe and does not require a structural customization. Positioning and sizing of linkage elements may deserve attention during planning/design phases, to limit flexural stresses in the screws and excessive stresses in the flaps.

The reduction of strain in the operated limb might suggest a risk of bone resorption, which would be however entirely due to asymmetric unloading of the operated limb, and not to prosthesis strain-shielding. An effort should be therefore directed towards an efficient post-operative rehabilitation of the operated limb to balance load distribution between the two limbs.

References

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