Topology optimization and additive manufacturing in acetabular implant design

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ABSTRACT

Modern additive manufacturing techniques have made it possible to have good control over a material's microarchitecture. In the context of implant design this gives the opportunity to address one of the main complications experienced after total hip arthroplasty, i.e. aseptic loosening[1,2]. This failure of the bond between implant and bone in the absence of infection is usually a result of the mismatch between the bone and the implant material properties. The mismatch leads to implant induced stress shielding, a trigger for bone resorption and the main culprit of aseptic loosening. The only solution after implant loosening is performing a revision surgery. These surgeries are complicated by the degraded bone quality and the presence of developed bone defects. Moreover, revision implants have worse prognoses than primary implants. In an aging population where it is bound to impact the quality of life of a growing segment of the population it is thus imperative to improve the current state of the art in implant design.

With this in mind, we have implemented a topology optimization approach that seeks to address the problem of aseptic loosening in revision implants for large acetabular defects. First two patient-specific finite element (FE) models are derived from a computerized tomography scan of the pelvic region of a healthy patient: one of the intact joint (reference) and one of the joint with its revision implant. To this end, the bony structures of the joint are segmented using Mimics 21 (Materialise NV, Leuven, Belgium). A defect is then created artificially in the acetabulum and reconstructed with the help of a statistical shape model. The reconstructed geometry is taken to be the design domain of the acetabular revision implant. CAD models of the femoral side of the implant are subsequently digitally implanted together with the acetabular polyethylene insert to obtain the initial implanted joint geometry. The FE-models are then generated from the corresponding geometries with an in-house MATLAB script (The MathWorks Inc., Natick, MA, USA) that makes use of the gptoolbox[3]. Models are fixed at the pubis and iliac spine and the joint loading is taken from the Othoload database[4]. Material properties of the bony parts are derived from the CT-scan grey values using Bonemat 3.2 (Istituto Ortopedico Rizzoli, Bologna, Italy). The models are then used in a modified version of the TopOpt in PETSc framework[5] to minimize implant-induced stress shielding in the pelvic bone subject to constraints on bone and implant stresses. Finally, the optimized Young's modulus values are translated to a scaffold structured implant to be additively manufactured. Computations are performed on the Flemish Supercomputer using ~1500 cores.

The described framework has been implemented and benchmarking and validation are taking place with artificially created cases, after which, we plan to also apply the framework to real clinical cases.

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REFERENCES

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