論 文 の 要 旨

題 目 Stress minimization of artificial bone using Non Parametric Optimization

(ノンパラメトリック最適化を用いた人工関節の応力最小化)

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The enhancement of orthopedic mechanical and medical lifetime is a matter of intensive study for almost 4000 years. The most important aspect of orthopedics is the body rejection. The body rejection of orthopedics is cleared by phenomenon refer to as stress shielding. Stress shielding is simply prescribed as, the osteointegration between the bone and the orthopedic start to deteriorate with time, such that the bone is dissolving exposing the orthopedic. The generated soft tissue and the mobility of orthopedic is a serious problem. The osteointegration problem is addressed with wolfs law. In this work, long term osteointegration is being addressed by two strategies i.e. the stiffness matching, and strain energy minimization of bone itself. In the first strategy, the orthopedic is designed and optimized to have a similar stiffness to the substituted bone for the designated loading and boundary conditions. The second strategy is to design the orthopedic with the constrained of minimizing the strain energy equivalent (Haigh stress) in the bone that produced by the force transfer from the orthopedic to the surrounding bone. In order do the orthopedic design, shape and topology optimization are investigated to have the optimal configuration and design scenarios. The suggested scenarios of topology optimization are divided into two categories. First category is the objective function investigation. The second category is the choice of shape optimization, topology optimization, or combination of both. Objective function been chosen are compliance, qp stress and pnorm stress, and fatigue life-based function. Finite element, and objective functions configurations are being studied. Topology and shape optimization were compared. Mesh morphing is being used as shape optimization method such that, it is used as medical based finite element modeling enhancement method, add to that the anticipated speed. Cascade method of topology optimization-shape optimization, and shape optimization-topology optimization models are being investigated. Due to the specifications of orthopedic designs requirements, and objectives, both mechanically and biomechanically, Topology optimization is being chased as the appropriate generalize methodology of design.

Two medical examples are chosen to simulate and investigate. First model is the temporomandibular joint prosthesis. Treatment of bone tumors in the mandible often involves extensive excavation of affected bone, followed by mandibular reconstruction. Prosthetic implants that been investigated is needed to restore jaw functionality. The challenges of making prosthetic bone implants include long term osteointegration and extending the mechanical life of the implant is the main goal. Temporomandibular case studied the stiffness matching hypothesis. Topology optimization is perfumed of a computer generation of the missing bone. Occlusion mismatching is a challenging problem in maxillofacial surgery. By making the design domain match the exact bone topography, high precision machining can give an exact replica of the jaw part to achieve an accurate occlusion. Model is decided to non-design domain which is the aesthetic, and biomechanics compatibility. The design domain is the inner part of the prosthesis. A simulation of orthodox used orthopedic is performed. Pnorm with stiffness matching constraint, and the compliance maximization with stiffness matching constraint are been chosen as optimality criteria. Pnorm showed good anticipated fatigue life with stiffness of the design orthopedic, matches the missing bone. The material we used was titanium alloy (Ti-6Al-7Nb). Volume fraction of the orthodox implant was used (0.2872 for the studied case) as volume constraints. The volume constraint is being chosen such that the weight of the titanium alloy should not be heavier than the replaced bone for the best weight compatibility. Compliance of the bulk bone was set as a further constraint to match the stiffness of the bone with the designed structure. Results show a good life expectancy for the designed parts, with 12% higher life expectancy for stress-based topology optimization than for compliance-based topology optimization. Design using topology optimization gave a long-life expectancy in the simulation process. The compliance objective function achieves good results for fatigue life prediction, but stress-based topology optimization achieves better results. The Orthodox-based design has a shorter life expectancy than the new optimized designs. Compliance of the orthodox design is almost 210% differ from the original replaced bone. Therefore, stress shielding of orthodox designs is highly desirable. From the design time aspect, maximizing compliance can be considered to be a faster strategy. Anther medical case been chosen is the topology optimization of the orthodox femoral hip joint implant. The hypothesis of stain energy is being chosen to limit the stress shielding i.e. increase the osteointegration strength. The minimization of pnorm of the Haigh stress of the surrounding bone was the objective function. Topology optimization of solid core orthopedics and conformal lattice structure-based scaffold were studied. Solid core orthopedics showed better minimization of Haigh stress in the surrounding bone. An investigation of surface modification of simulated rapid prototyping structure is being performed. Electropolishing by precipitation is simulated. The simulation of loaded polished structure showed better limitation of the spots of singular stresses. In the scope of the results, algorithms are been introduced in order to efficient the design and manufacturing of fully custom orthopedics in shortest time as possible in the scope of the current software simulation and 3d metal printer capability.