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Opinion

# CHIDOS: Customized Hip Implant Design & Optimization Service

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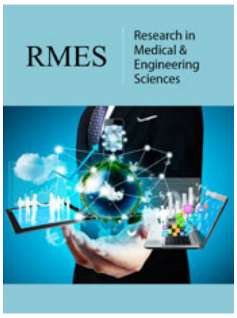

### Abstract

CHIDOS is a web application that conducts artificial intelligence (AI) - empowered customization and Finite Element Analysis optimization (FEA) of additively-manufactured hip implants used in total hip arthroplasty. The medical practitioner only creates a patient profile, uploads the patient's CT scans and confirms the anatomical landmarks that are necessary for the restoration of the patient's hip biomechanics. Based on this information, CHIDOS automatically reconstructs the anatomy of the patient's pelvic and femoral bones in a 3D digital environment, develops a patient-specific femoral stem as well as patient-specific surgical tools (i.e., broach/rasp, osteotomy guide) used in total hip arthroplasty, optimizes the implant's design, and creates accompanying 3D documentation & 3D anatomical models of the hip joint, useful for preoperative planning and intra-operative guidance. The patient-specific femoral stem developed may be combined with several commercial acetabular cups and femoral heads based on patient's needs and surgeon's experience. The reconstructed femoral stem, anatomical models and the surgical tools are all designed in a completely automated pipeline and produced via additive manufacturing.

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## Opinion

Total Hip Arthroplasty (THA) is the most common orthopaedic surgery [1] with one million surgeries performed worldwide each year-153 per 100,000 population in Europe [2]. In THA, the head of the femur is replaced by an artificial stem and ball system, which is available in a variety of materials, such as titanium and cobalt chromium-alloys. The stem is inserted firmly into the shaft of the femoral bone and fixated either using acrylic bone cement, or by osseointegration. The wide range of stem designs available allows for a strong degree of customization to account for individual patient anatomies. The choices made, and consequently the success and longevity of the implant, however, depends solely on the knowledge and expertise of the orthopaedic surgeon [3]. The scientific case for CHIDOS is to provide a holistic solution that optimizes THA workflow to make it cheaper, faster, and more accurate. It supports the surgeon in choosing the optimal prosthesis for the patient's anatomy and ease the ordering and delivery for cases where prostheses need to be custom-designed and manufactured.

Design of custom hip prosthesis, according to computer tomography (CT) images, has been introduced in many articles [4-13]. The authors stress that taking the bone internal remodeling phenomenon into account during the process can lead to a reduction in the number of implant failures. CT data is used for reconstruction of the patient's femur model. From the anatomical shape of the medullary canal the form of a tight-fitting endoprosthesis stem is defined [6-7,13]. The recommended form and dimensions are derived from the anatomical features of the patient. The fit-and-fill principle is one of the earliest design rationales in the evolution of cementless femoral stems. This premise is based upon maximizing contact area of the stem with host bone to achieve the greatest fixation stability and optimal long-term osseointegration. The fit-and-fill approach has been validated to be valuable in providing long-term, pain free and more suitable implants [12]. CHIDOS uses a modified fit-and-fill approach to improve its mechanical stability and longevity and restore the patient's desired anatomical posture (Figure 1).

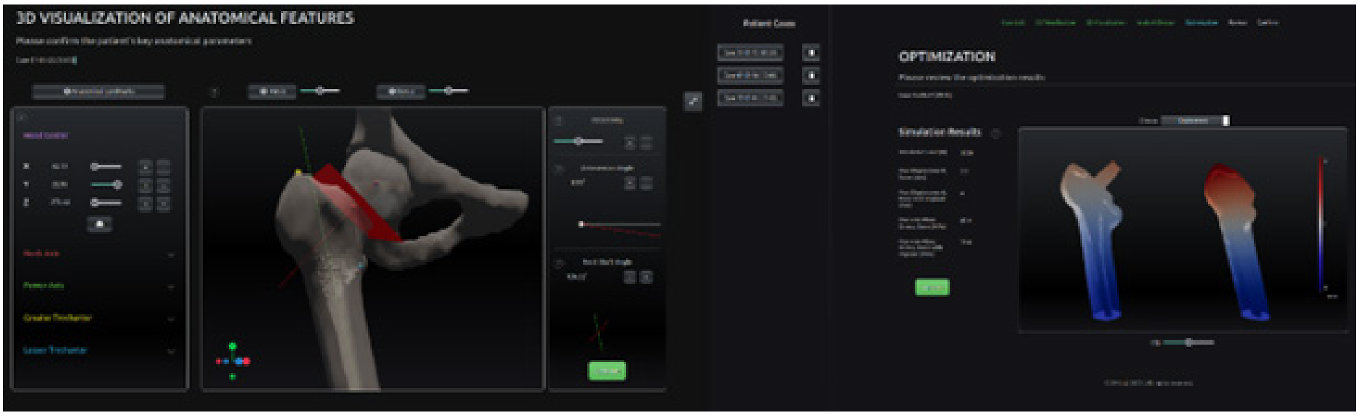

**Figure 1:** CHIDOS osteotomy definition interface and FEA optimization results preview.

After the 3D reconstruction, anatomical parameters of the femur are extracted, contributing to the custom implant design. The neck osteotomy follows depending on the bone size of the patient, the neck angle, and preoperative planning. Next, implant design options are selected. The distal segment of the implant depends on the shape and dimensions of the medullary canal, thus ensuring that the implant can only be placed at the predetermined position within the femur. The mid segment of the endoprosthesis body provides its proper positioning, enables the transfer of the load from the pelvic region to the foot and ensures osseointegration. The proximal part is sized to fit the head and acetabular cup and can feature a collar if selected. Trabecular surfaces based not only on geometrical patterns but also on the structure of cancellous collagen itself (with the intent to further promote osseointegration) are automatically designed with the density selected by the surgeon and incorporated into the mid-segment of the stem. All implant segments are automatically designed based on the parameters calculated before. Customised broaches based on the stem's exact geometry are also automatically designed in any type required. Optionally the surgeon can choose to optimize the implant structure using Finite Element Analysis to continuously modify the design until its mechanical behavior is as close to that of the intact femur (also analyzed with FEA) as possible. The results are automatically evaluated, the objective function is calculated and fed into an optimization algorithm. The objective function's terms are:

a) Elimination of the Stress Shielding effect in the implanted femur by matching stress distributions,

b) Minimize the stiffness mismatch between femur and the stem, which can lead to excess stresses in the implanted bone. This can be achieved by minimizing the difference of the maximum induced displacement between the intact and the implanted femur.

c) Minimize the mass to volume fraction of the femoral stem.

The algorithm modifies the implant's design parameters and initiates a new design-analysis-optimization cycle. It is worth noting that variable internal lattice structures, of variable sizes and density, some based on mechanical and some on natural lattices, are tried out during this process. This is repeated until the objective function has been minimized, or until changes offer negligible reductions of the function.

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