Combined statistical model of bone shape and mechanical properties for bone and implant modeling

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Current design process for orthopedic implants relies on limited knowledge about shape and mechanical properties of the bones of interest. Nowadays, implant design is based on reduced information deriving from literature (e.g. bone angles and lengths) and does not take into account differences among populations (ethnicity, height, gender ...). For these reasons we propose a method to model bone shape and/or density variations for different populations.

The proposed model is based on recent advances in image processing to create compact mathematical representations of bone anatomy. About 200 CT images were collected from patients of different ethnic group, sex and age. These images were segmented and registered rigidly - to align the bones in the same coordinate system - and non-rigidly - to find the anatomical correspondences among them. The non-rigid registration was performed in the Log-Domain to ensure smooth and invertible deformation fields. Based on this registration, a statistical shape/intensity model was built to compute the average bone, variations of bone shape across the population and to generate new bone instances.

The developed model was used to assess the fitting of orthopedic plates to the proximal tibia. Results showed that the implant better fitted the Caucasian population than the Asian one; this was expected since the implant was initially designed based on the Caucasian population. However, the geometric relationship between bone and implant is not sufficient to ensure implant success – the mechanical behavior of the bone/implant construct should also be considered. Therefore, finite element calculations were performed on instances generated with the statistical shape/intensity model. Results showed that stresses in the plate and screws were significantly lower for the Caucasian implant than for the Asian one. The combination of statistical shape/intensity model and finite element calculation is therefore a powerful tool to assess orthopedic procedures and implant design.