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Intra-Operative Visualization And Assessment Of Articular Surfaces In C-Arm Computed Tomography Images

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The use of intra-operative 3D imaging is more and more becoming a standard process in orthopedic surgery. By providing better spatial visualization with nearly the image quality of a conventional CT scanner the C-arm CT can help the surgeon to verify the results of the surgery and thus reduces the need for second interventions. In literature, the intra-operative C-arm CT is widely acknowledged as the most feasible method for verification in orthopedic interventions. However, the greatest benefit, the mobility, also causes the biggest problem while using this type of device. The lack of information of the patient-to-device orientation causes the need for an adjustment of the standard image planes at a workstation in the operating room. The adjustment demands a new set of skill from the surgeon and especially inexperienced users need a long learning period to accurately handle the image adjustment and the following assessment. Even if the standard planes are adjusted correctly a correct assessment of the gray-scale volumetric images in the operating room is a difficult task. In the pre- or post-operative case, this is done by a radiologist who is specialized in the navigation of volumetric images and has a calibrated computer screen.

This work addresses the above mentioned problems by providing different methods for the semi-automatic and automatic adjustment of the standard planes and an independent advanced visualization as assessment assistance of C-arm computed tomography images using the example of intra-articular calcaneal fractures. The assessment focuses on the articular surfaces with respect to deformations caused by not anatomically reduced bone fragments.

An exact adjustment of the standard planes is necessary for the best possible visualization and evaluation of the anatomical region of interest. As manually done, this can be a time-consuming process. A first semi-automatic approach based on anatomical landmarks has been developed after reviewing the workflow and adjustment in the operating room. The medical workflow in the operating room was observed before an actual concept and the method for the implementation were chosen. Three surgeons of different expertise adjusted the standard planes on a clinical data set consisting of 51 images of intra-articular calcaneal fractures of varying complexity (Sanders type II to IV). The adjusted planes of the images are used for the atlas used in the registration process.

In an iterative process three automatic methods (slice-wise 2D SURF key points, pseudo-3D SURF key points and 3D SURF key points) for the adjustment have been developed all based on SURF key point detection followed by a rigid atlas registration using the ICP algorithm. With each method, the accuracy of the adjustment could be increased and all methods are much faster than the manual adjustment in the operating room which was verified with the manual adjustments of three surgeons with different expertise (two expert users and one intermediate user). The adjusted planes were evaluated using a clinical data set. Additionally,

the impact of the image resolution, metal implants and artifacts was evaluated by testing the algorithms performance with two different image resolutions (256^3 and 512^3) and two different methods for metal artifact reduction (inpainting and FSMAR). The higher resolution provided slightly better results but the metal artifact reduction did not improve the results.

In the second part of the thesis builds an automatic assessment of the articular surfaces (subtalar and calcaneocuboidal) of the calcaneus with respect to deformations caused by not anatomically correct reduced bone fragments is proposed. The developed automatic approach uses three steps with the adjusted standard planes as input. First, the joint space is localized by an intensity profile search. In a second step, a segmentation of the whole volumetric C-arm CT image based on a LoG approach is generated. By using the localized joint space as a seed point the segmentation is circumscribed to the articular region with a modified version of the flood fill algorithm called flood segmentation. In the last step a surface model of the articular region is generated and the articular surface of the calcaneus is extracted. By using a color-coded visualization and a difference map displaying the deviation of the input surface from an unfractured surface a first assessment can be done with highlighting of critical deformations.

In order to have enough data of anatomically incorrect reduced fractures a human cadaver study was conducted consisting of 30 lower legs as from clinical data no reliable information on the size and width of deformations can be retrieved. It was possible to acquire realistic C-arm CT images of misaligned bone fragments with varying severity and the acquired data was used to evaluate the correctness of the assessment which is crucial to prove the feasibility of the proposed methodology. The developed assessment of the articular surfaces showed very good results on this data set qualifying for intra-operative usage and greatly simplifying and improving the assessment of the gray value volumetric images.

The automatic adjustment of the standard planes and the assessment of the articular surfaces deliver an intuitive simplification of the current manual C-arm CT usage. By using the proposed methods in the clinical workflow it is not only possible to reduce the overall surgery time and highlight critical areas after image acquisition, also the cost for the intervention and the time of the patient being under the influence of anesthesia is reduced and the error prone assessment of the gray value images is improved.