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Computer-assisted Total Hip Arthroplasty: from Pre-operative Planning to Post-operative Assessment

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Introduction

Total Hip Arthroplasty (THA) surgery restores the articulation mobility and stability by implanting a prosthetic hip joint. The selection and positioning of the implant are critical in THA. Conventional planning seeks the optimal selection of implant characteristics by relying on a “static” approach which only exploits anatomical cues derived from a plain radiograph or a CT scan. Dynamic aspects are indeed neglected, such as pelvic tilt during postural changes and the necessary motion of the prosthetic hip to yield a satisfactory range of motion (ROM) in everyday life.

Despite an adequate planning is produced, its execution during the surgical act remains problematic, since intra-operative guidance is not commonly provided. As a result, the effective positioning of implants may significantly deviate from the planning. A post-operative assessment of the prosthetic hip is hence necessary to investigate the quality of the surgery.

We present our computer-assisted framework “MyHip” for THA. The framework provides intra-operative assistance based on personalized guiding blocks. However, we will not cover in this paper this intra-operative support; instead we will focus on the pre-operative planning and post-operative analysis.

Methods

Pre-operative planning

In the pre-operative stage, we reconstruct the bones of the patient’s hip joint from a CT image. We usually adopt a semi-supervised segmentation. First, an automatic segmentation is applied (e.g., intensity thresholding or a more advanced method like our approach based on physically-based deformable models [1]). Second, we perform possible manual corrections to refine areas of interest (e.g., acetabulum area) and correctly tackle pathological areas. Pathological areas are recurrent in operated hips and they affect the accuracy of automatic approaches (deviation from “normal” intensities and morphology).

Based on a first planning provided by the surgeon, implant components are positioned in the reconstructed models and a virtual resection of bones is applied (femur cutting and hip bone reaming). Subsequently, a possible pelvic tilt correction is applied to update the planning accordingly. Pelvic tilt is estimated by a lateral radiograph (Fig. 1a) with the patient standing up and it provides important information on postural changes [2].

Finally, the planning is tested in a dynamic simulation. The virtual prosthetic hip is animated with a set of hip movements. This simulation computes the hip ROM and detects any articular conflicts (e.g., collisions, excessive subluxations) resulting from the planning (Fig. 1b). With this information, the surgeon adapts and refines the initial planning. Movements were previously recorded on volunteers with optical motion capture technology whose anatomy was reconstructed from MR acquisitions [1]. Movements were selected from activities of daily life known to be prone to implant failure [3].

Post-operative assessment

Like in the pre-operative stage, prosthetic hips are reconstructed from post-operative images. Since the patient hip was pre-operatively created, the segmentation is equivalent to a model-to-image rigid registration. The rigid registration exploits a constrained version of our physically-based deformable models [1]. The models (CAD models of implants, pre-operative segmented bone models) are coarsely initialized in the images based on manually placed landmarks. Then, all models simultaneously evolve in a dynamic evolution where gradient forces are applied to attract models towards the boundaries of interest. A rigid regularization is performed after each time step of the dynamic evolution to prevent model deformation. Similarly, the implant stem is constrained inside the socket of the acetabular liner by maintaining coinciding model centers. Eventually, a manual segmentation is performed to remove the bony areas that were effectively resected during the surgery. Fig. 1c depicts a segmentation result.

Results

We studied the effects of implant selection, morphology and motion on impingements, joint congruence and ROM [3] based on motions captured from 4 subjects. A strong correlation between the frequency of impingements and implant characteristics was reported. Another experiment with 2 patients highlighted the importance of considering the pelvic tilting in the planning. Indeed, when the tilting was not taken into account, more impingements (+10% of avg. increase) and more significant subluxations (+3 mm in average) were observed.

Post-operative analysis showed the difficulty to always reproduce with accuracy a planning when no guidance was provided. For instance, we computed the anteversion (A) and inclination (I) cup angles from 3 male patients and observed the differences with planned values. Fig. 1d illustrates one patient with planned values of 15°(A)/45°(I) and post-operative angles of 21°(A)/38°(I). Conversely, we observed a good agreement between the planned and achieved femoral resection when intra-operative guidance (femoral cutting guide) was provided (Fig. 1e).

Conclusion

We presented a computer-assisted framework for THA. Despite a limited number of subjects, the conducted experiments underpinned benefits of using a dynamic simulation to select the best implant characteristics based on the patient morphology, posture and activity lifestyle. This approach produces a more personalized planning. Similarly, post-operative analyses supported the need of better intra-operative guidance to execute at best the planning. To avoid the use of invasive post-operative CT images we are current validating an alternative approach that will reconstruct models from post-operative radiographs.

References

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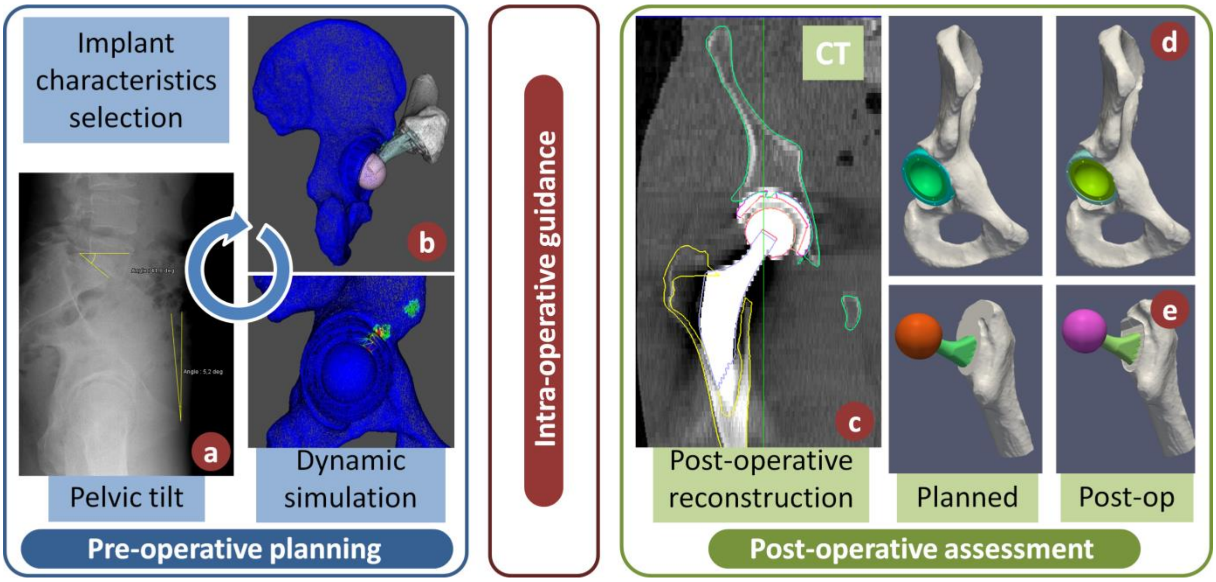

Fig. 1 MyHip computer-assisted framework