Computer-assisted pre-operative planning for hip joint-preserving surgery

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INTRODUCTION

Femoroacetabular impingement arises from the abnormal shape of the femoral head and/or acetabulum. By reducing the increased radius of the femoral head and the ossified acetabulum, impingements of the hip joint can be removed. And more, periacetabular osteotomy is an effective way to reorient the acetabulum in young adults with symptomatic anterior femoroacetabular impingement due to acetabular retroversion. [1] As a diagnosis and a pre-operative planning of joint preserving surgery for the treatment of the femoroacetabular impingement, we implemented bone reshaping process in a computer system. It included a diagnosis of impingements based on the morphology. By using our planning system, surgeons could select the region to cut and could pre-assess impingement-free motions.

METHODS

We used 4 steps to fulfill the diagnosis and a pro-operative planning of surgical treatment. It composed of the reconstruction of three-dimensional bony model, incorporation of joint kinematics, bone reshaping, and range of motion computation.

1. Reconstruction of three-dimensional (3D) bony model: As we were interested in young patients with incipient disease, we used Magnetic Resonance (MR) images. We are considering patients without radiographic signs of osteoarthritis. For the diagnosis of the symptoms, we developed both bone-specific and cartilage-specific imaging method. From MR Images, we reconstructed a pelvis and a femur model. For the accuracy in the hip joint region, different slice thicknesses were considered. Four series of spin-echo images were obtained for each specimen using a 1.5T Intera MRI system (Philips Medical Systems, Best NL) at the Hospital University of Geneva. The thickness of MR images is 6mm for the Iliac (gap between slices: 0.6mm), 2mm between the femoral head to the femoral neck (gap: 0.5mm), 12mm for the rest of the femur (gap: 0.6mm), and 4mm for the knee (gap: 0.9mm). We manually outlined the boundaries of the bones in each image slice. Three-dimensional surface models were generated by connecting adjacent contours with a polygonal mesh.

2. Incorporation of joint kinematics: The surface models were imported into a graphics-based in-house functional planning system. Coordinate systems were established for the pelvis and femur based on anatomical landmarks [2]. Kinematic descriptions of the hip were defined for each model based on the bone surface geometry. A temporary hip joint center (HJC) was located by fitting a spherical shape on the acetabular rim region, which shows a more spherical shape than the femoral head. Pivoting this temporary initial HJC circumduction motions were simulated. If there was a collision between the acetabular rim and the femoral head during motions, another candidate has been selected.
candidates for the HJC were in array of points separated by 0.1mm in a cube of side 3mm. An iterative process was performed until there was no collision between bones. [3]

3. Bone reshaping: 3.1 Femoral head: By fitting a sphere which covering all the vertices of femoral head and measuring the distance between the center of a sphere and the vertices, we could analyze the region to be cut. Thus, the femoral head-neck junction could be cleared from the impingement. 3.2 Acetabulum: The bony rim of the acetabulum could be decided by impingement test, and it could be resected interactively by plane cutter with free angles until the over-covered region had been removed. It was the same function as an osteotome is used in a real surgical process. 3.3 Periacetabular osteotomy: 12 control points were added periacetabular region of our planning system. Osteotomy line was represented as a series of points that were fit with a Kochanek–Bartels cubic spline [4]. Users could control this line by manipulating control points interactively.

4. Range of motion (ROM) computation: Our planning system allowed three plane motions (Rotation, Flexion/Extension, and Abduction/Adduction), successive motions (e.g. 90° Flexion and rotation) and circumductions. By combining impingement detection tools, we could calculate specimen’s range of motions.

RESULTS
Subject specific bony models and pre-operative planning tool have been implemented. Models were navigated in a user-friendly way and the femoral head shape was colored as a distance from the center of the sphere, so the bumpy region was easily detected. Moreover, ROM could be assesses before and after the osteotomy in this system. This system was developed based on the young healthy volunteers’ MR Images (mean age: 28.3 (S.D. 3.6)), so we could reduce the exposure of radiation. The developed system could provide essential hip kinematics and factors influencing hip ROMs, particularly in extreme hip positions.

DISCUSSION
For every patient, impingement-free motions need to be achieved based on a correct pre-operative planning system. By using our system, a surgeon can examine the 3D models prior to surgery, obtain a proper visual result, and generally reduce the overall time of the surgical operation. Thus individual (per patient) correction can be achieved and the range between under-correction and over-correction can be narrowed. Surgeons can predict the regions where impingements occur and can compare the range of motions before and after cutting. Even though we presume that our system, developed based on healthy volunteers’ dataset, could be applicable to group of patients, the system needs to be always adapted to the patient’s dataset. Considering the large range of differences of the patient’s individual clinical and radiographic variables, the alternative treatment should be taken into account.

REFERENCES

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