Cadaveric validation of a novel planning and navigation system for peri-acetabular osteotomy (PAO)

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***Abstract**:*

This paper presents a cadaveric validation of a novel planning and navigation system for peri-acetabular osteotomy (PAO). In total 8 computer assisted PAO procedures was performed on 4 cadavers (each cadaver has two hip joints). By comparing the pre-operatiely planned situation and the intra-operatively achieved situation, an average error of 0.65°, 0.56° and 0.91° was found respectively along three motion components: External Rotation/Internal Rotation, Abduction/Adduction and Extension/Flexion.

Key words: Peri-acetabular Osteotomy, Navigation, Validation

1 Introduction

Periacetabular osteotomy (PAO) is an effective approach for surgical treatment of painful dysplasia of the hip in younger patients [1]. The aim of PAO is to increase acetabular coverage of the femoral head and to reduce contact pressures by realigning the hip joint [2, 3].
It was reported that the most challenging aspect of PAO surgery is to achieve the optimal alignment [4]. Rodriguez et al. [5] presented an experimental cadaver study for performance of periacetabular osteotomies. They examined how accurately a preoperatively planned angular and rotational acetabular reorientation could be realized. Transfer of this knowledge to the clinical setting has never been performed. Hsieh [6] et al. report on intraoperative application of CT based navigation systems. In their study, the examiner has to manually digitize the acetabulum for registration purposes, which is an error prone procedure. Jäger [7] presented a study treating patients with a triple osteotomy, using a CT based navigation application. There was however no statistical evaluation of accuracy of acetabular reorientation. Langlotz et al.[8] report on a first computed-tomography (CT) based navigation application for periacetabular osteotomy. This pioneer application offered visualization of the periacetabular cutting planes and assisted the surgeon during reorientation of the acetabulum and was applied in 14 clinical cases. However the application did not allow for preoperative planning of the procedure and the surgeon could not refer to standard parameters defining acetabular orientation. Hence, despite showing sufficient registration accuracy, the authors could not perform statistical analysis verifying accuracy of the procedure. In this paper, we present a cadaveric validation study of a novel planning and navigation system for PAO.

2 Materials and Methods

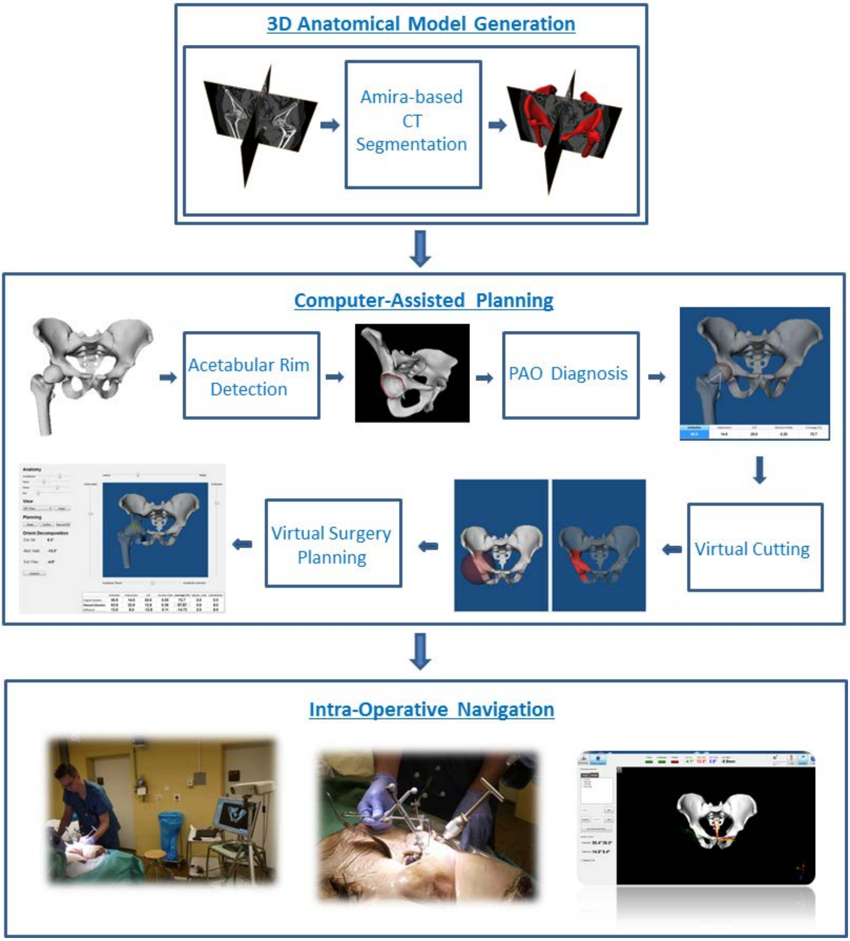
The comprehensive planning and navigation system for PAO consists of three modules as shown in Fig. 1.

- Model generation module. 3D surface models of the femur and the pelvis are generated from a pre-operatively acquired CT data using a commerically available segmentation program (AMIRA, Visage Imaging, San Diego, USA).

- PAO planning module. The aim of this module is to allow the virutal simulation of the reorientation procedure using the surface models generated from the model generation module. It starts with a fully automatic detection of the acetabular rim, which allows for computing important information quantifying the acetabular orientation such as coverage, extrusion index, lateral centre-edge (LCE) angle, version and inclination. This module provides a graphical user interface allowing the surgeon to conduct a virtual osteoomy and to further reorient the acetabular fragment until an optimal realignment is achieved.

- Intra-operative navigation module. Based on an optoelectronical tracking technique, this module aims for providing intra-operative visual feedback during acetabular fragment reorientation until the pre-operatively planned orientation is achieved.

In order to validate this newly developed planning and navigation system for PAO, a cadaveric study was conducted. In total 8 computer assisted PAO procedures was performed on 4 cadavers (each cadaver has two hip joints). Pre-operative planning was conducted with the PAO planning module. Subsequently the intra-operative navigation module was used to track acetabular and pelvic fragments, supporting and guiding the surgeon during the osteotomies around the acetabulum. After separation of the acetabular fragment from the pelvis, the navigation system then



guided the surgeon during the reorientation of the acetabulum until the pre-operative plan was achieved. Acetabular reorientation measured by the version and inclination Angle can be planned preoperatively and subsequently realized intraoperatively without significant difference. In order to assess the error difference between the pre-operatively planned and the intra-operatively achieved acetabular orientation, we compared the decomposed rotation

Figure 1:. Pipeline of the comprehensive planning and navigation system for PAO.

components derived from the acetabular fragment reorientation between the planned and intra-operative situations because the instant version and inclination Angle correspond a specific decomposed rotation components of acetabular fragment.

3 Results

As shown in Fig.2, the decomposed rotation components of the acetabular fragment between the pre-operatively planned situation and the intra-operatively achieved situation were compared. According to Table 1, 8 groups of acetabular reorientation data were obtained. It can be seen that the average errors along three motion components (External Rotation/Internal Rotation, Abduction/Adduction and Extension/Flexion) are 0.65°, 0.56° and 0.91°, respectively, which are accurate enough for PAO surgical intervention. The maximal error is from the 4_{th} cadaver with the biggest registration error. It was found that the 4_{th} cadaver has prosthesis implanted, which made it difficult to segment high quality model from its CT data. This is why mean error of the 4_{th} cadaver is slightly worse than those of the rest of cadavers.

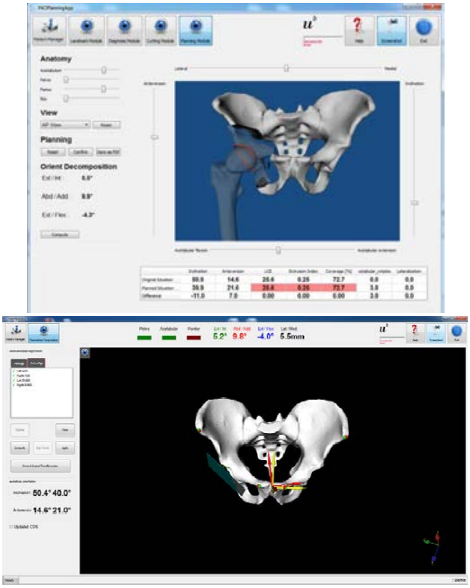


Figure 2: The decomposed motion components comparison between pre-operative planning and intra-operative navigation situations: (a) pre-operatively planned situation; (b) intra-operatively achieved situation.

		Mean Error		
		Ext / Int (°)	Abd / Add (°)	Ext / Flex (°)
Cadaver1	***left hip***	0.48	0.3	0.6
	right hip	0.72	0.61	0.63
Cadaver2	***left hip***	0.5	0.4	0.2
	right hip	0.26	0.2	0.1
Cadaver3	***left hip***	0.25	0.4	0.4
	right hip	0.4	0.9	0.45
Cadaver4	***left hip***	1.1	0.4	2.6
	right hip	1.5	1.3	2.3
	Average	0.7	0.6	0.9

Table 1: The error difference of decomposed motion components between pre-operative planning and intra-operative navigation situations

4 Conclusions

In this paper, we present a cadaveric validation of a comprehensive planning and navigation system for PAO. Our experimental results demonstrate the accuracy of this newly developed system. A clinical trial is planned to further validate the effacicy of the developed system for PAO interventions. Our experimental results demonstrated that there is no significant difference between the pre-operatively planned and final intra-operative acetabular orientation, measured by decomposed rotation angles. We concluded that preoperative planning and subsequent conduction of acetabular reorientaion in PAO is technically feasible and is associated with good accuracy in the experimental cadaveric setup.

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