A Patient-specific Navigational Template for Precise Acetabular Placement in Unilateral Total Hip Arthroplasty: A Cadaveric Study

Jinlong LIANG

People's Liberation Army Joint Logistic Support Force 920th Hospital

Xinjian Gao

Xi'an Jiaotong University

Xuewei Fang

Xi'an Jiaotong University

Yonghui Zhao

People's Liberation Army Joint Logistic Support Force 920th Hospital

Yongqing Xu

People's Liberation Army Joint Logistic Support Force 920th Hospital

Sheng Lu (✉ lushengdr@163.com)

<https://orcid.org/0000-0001-7532-8981>

Research article

Keywords: Custom-made navigational template, Total Hip Arthroplasty, Computer Assisted Surgery, Rapid Prototyping, Hip joint center

Posted Date: May 8th, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-26022/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Abstract

Background

Total hip arthroplasty (THA) is a widely performed reconstructive surgical intervention. In this paper, we describe a novel patient-specific navigational template to assist in acetabular component implantation in unilateral THA.

Methods

The template was produced based on data preoperatively acquired with computed tomography (CT) scan. We used the mirror image of the healthy contralateral acetabular anatomical structure to ensure accurate acetabular component implantation in unilateral THA. The surface of the template was designed to conform to the unique contours of the cadaveric acetabular fossa by reverse engineering technology. The orientation of the navigation channel was defined by the acetabular central axis which was determined by the contralateral acetabular centre of rotation, anteversion angle and abduction angle. Each template was formed from acrylate resin by using rapid prototyping (RP) technique. Finally, the template was tested in 20 cadavers scheduled for unilateral THA and postoperative medical imaging was used to evaluate the accuracy and validity of the template.

Results

During the operation, the acetabular fossa template was easy to obtain in all cases. The abduction angle (β) of the cup was ($49.9^\circ \pm 4.1^\circ$) versus ($49.5^\circ \pm 4.7^\circ$) on the contralateral side. The anteversion angle (α) of the cup was ($17.7^\circ \pm 3.1^\circ$) versus ($18.3^\circ \pm 3.5^\circ$) on the contralateral side. In the operative hip, the height of the prosthesis centre(H)was ($21.6 \text{ mm} \pm 2.8 \text{ mm}$) versus ($21.9 \text{ mm} \pm 3.4 \text{ mm}$) in the contralateral side, and the horizontal location of the prosthesis centre(W) was ($29.7 \text{ mm} \pm 3.1 \text{ mm}$) versus ($30.90 \text{ mm} \pm 3.31 \text{ mm}$) in the contralateral side. There was no significant difference in the cup abduction (β) or anteversion (α) angle between the operative and contralateral sides ($P=0.7531>0.05$ for β and $P=0.5996>0.05$ for α); In addition, there was no significant difference in the height(H)or horizontal location(W) of the acetabular centre between the operative and contralateral sides ($P=0.6494>0.05$ for W and $P=0.5143>0.05$ for H).

Conclusion

The navigational template is a promising tool for facilitating preoperative planning and intraoperative techniques. With the aid of the template, an acetabular prosthesis can be precisely implanted to the expected position in unilateral THA.

1. Background

Total hip arthroplasty (THA) is a well-documented treatment that provides pain relief and functional restoration to numerous patients suffering from hip joint disease^[1,2]. THA surgeries are most frequently used among elderly and less active patients^[3]. In recent years, the demand for THA in younger patients

has increased rapidly^[4]. Accurate restoration of the orientation of the acetabular cup plays a critical role in the surgical procedure of arthroplasty^[5]. Any displacement of the acetabular cup from its ideal centre can negatively affect both prosthesis survival^[6], and the range of motion of the hip joint [7].

Due to the variability of anatomical and morphological features among patients, the uniform manufactured joint prosthesis and standard operation procedure cannot meet individual needs. With the development of computerized navigation and additive manufacturing technologies, computer-aided operations have become increasingly popular over the past few years. We performed preoperative planning with a novel patient-specific navigational template to assist in accurate acetabular component placement in a cadaveric study of unilateral THA, based on computed tomography (CT) data.

2. Methods

2.1 Data Acquisition

Twenty cadavers with intact hips (12 males and 8 females), were collected from the Department of Anatomy at Kunming Medical University. The mean age of the deceased was 52.5 y (range: 41–68 y). The hips were examined using standard radiographs, which showed hips with partial normal anatomy and varying degrees of dysplasia and degenerative osteoarthritis. A spiral 3D CT pelvic scan (GE, LightSpeed 64-Row, VCT, USA) was performed on each cadaver, the slice thickness was 0.630 mm and the in-plane resolution was 0.35 mm (tube current: 100 mA; tube voltage: 120 kV; scan time: 15 s to 20 s). All imaging data were stored in the DICOM (digital imaging and communications in medicine) format. The need for ethics approval was deemed unnecessary for this cadaver research by the Ethics Committee of 920th Hospital of Joint Logistics Support Force.

2.2 Preoperative Planning

The images were transferred to a workstation running MIMICS10.01 software (Materialise, Belgium) to generate a 3D model of the desired pelvis. The 3D model was exported in standard template library (STL) format which is constructed with a series of triangles and is the de-facto criterion format for data exchange between the computer-aided design and computer-aided manufacturing (CAD/CAM) system and the rapid prototyping and computer-aided engineering (RP&CAE) system. We then used a workstation running UGS Imageware13.0 (EDS, Plano, TX) to extract the point cloud of the contralateral acetabulum. The point cloud is the collection of point data expressing the spatial distribution of the surface and characteristics of the model appearance under the same reference frame. The STL format is the outcome of point cloud data triangulation.

By fitting a suitable sphere to the point cloud we obtained the coordinates of the spherical centre, the centre is defined as the rotational center of the contralateral acetabulum. Accurate results can be achieved through essential filtration of the point cloud and multiplex fitting approximation method. The deviation of fitting can be observed by error analysis (Figure 1). The [mirrorimage](#) is used to obtain a symmetrical

structure of the target model. In most cases, the normal bilateral acetabulum is nearly symmetrical according to the sagittal plane in the human body. It is a key problem to reconstruct the normal biomechanics of the acetabulum in THA, but it is difficult to locate the rotational centre of the acetabulum during operation. We then using the mirror image to determine the rotational centre coordinate of the operation side based on the contralateral acetabulum.

The acetabular central axis indicates the opening direction of the acetabulum and is considered the ideal implant channel for acetabular components. Determination of the acetabular central axis is based on accurate measurements of the acetabulum. We exported the 3D pelvic model to a workstation running 3-matic 6.1 software (Materialise, Belgium) to create the standard transverse and coronal section according to the bilateral acetabular centre of rotation.

Based on the projection of the pelvis on the coronary section, the abduction angle of the contralateral acetabulum(β) was denoted as the acute angle between the line connecting the bilateral acetabular centre of rotation and the long axis of the two edges of the projected shadow of the acetabulum (Figure 2A). If the projection of the pelvis is on the transverse section, then the complement angle is the anteversion angle of the contralateral acetabulum(α) (Figure 2B).

Generally, the acetabular central axis is considered the expected channel of acetabular component implantation in THA. In our study, the coordinates of two points were located, as follows, one was the symmetry point of the contralateral acetabulum, the other was calculated using a trigonometric function and named after the senior author LJL, This second point was denoted as “L” point(Figure 3).

The acetabular central axis is the line connecting the two points, and it is considered the axis of a virtual navigation channel expected to have an optimal location. Then, a virtual channel with a diameter of 4 mm was placed according to the ligature. This navigation channel is also the optimal trajectory for the guide pin that guides the acetabular reamer when polishing the acetabulum, thereby facilitating the accurate implantation of acetabular components. The template surface was created as the inverse of the acetabular fossa, thus potentially enabling a nearly perfect fit. We also ensured that the template did not overlap with adjacent segments. Then, an individualized version of the novel navigational template had been designed(Figure4).

The template was manufactured with medical-grade acrylic resin (Somos 14120, DSM Desotech Inc. USA) via RP (Bingchuang Company, China). The system parameters were set as follows: processing layer thickness, 0.1 mm, processing speed 450 mm/s, and temperature 45 °C $\pm$ 2°C.

2.3 Operation

All operations were performed by the senior authors (LJL, GXJ),repeating the same procedure in each case.

The specimen was placed in a lateral decubitus position on the dissecting table. The soft tissue around the hip joint was resected for better exposure. Then, osteophytes and other excessive tissue were removed in and around the acetabular fossa (Figure 5A). We subsequently matched the template to the surface of the acetabular fossa (Figure 5B). A 3 mm diameter guide pin was placed along the navigation channel, and after achieving an accurate fit, the template was stabilized on the bone. The central axis and the anatomical opening direction of the acetabulum was determined (Figure 5C). While we just penetrated the dome of acetabular cortex, the guide pin remained very stable throughout the debridement operation. We placed the guide pin with a limited depth into the acetabular dome intraoperatively, based on preoperative measurements. Controlled implantation of the guide pin can also be obtained by awareness of the empty feeling that occurs when the guide pin has penetrated the two cortices of the acetabular dome. Then the template was removed and the guide pin remained. We started reaming using a cannulated acetabular reamer we designed for the operation, thus, we could precisely match the guide pin. The modified acetabular reamer was used during the operation (Figure 6). The direction of the cannulated acetabular reamer was consistent with that of the guide pin. The acetabular prosthesis was then inserted along the track (Figure 5D).

2.4 Postoperative measurements and Statistical analysis

After the operation, the position of the acetabular prosthesis was evaluated through postoperative X-rays and CT images. All data were presented as the mean $\pm$ SD, and T-test was performed using Prism 6.0 software. The postoperative CT images were inputted to Mimics software. The centre of the operated side was the midpoint of the two endpoints of the cup on the axial CT images; and the centre of the contralateral acetabulum was the centre of the suitable fitting sphere of the acetabulum we reconstructed. The measured parameters were as follows: (1) the anteversion angle of the cup prosthesis (α) was the coangle between the line connecting the bilateral acetabular centre and the ligature of the two endpoints of the cup image on the transverse section; and (2) the abduction angle of the cup prosthesis (β) was the acute angle between the two connecting lines as described above on the coronal section (Figure 7).

Then the postoperative X-ray images were imported into the AutoCAD 2010 software (Autodesk, USA) software. We reconstructed a fitting circle for the contralateral acetabulum, and the centre of the circle was considered as the centre of the contralateral acetabulum. The centre of the acetabular prosthesis was the center of the opening ring of the cup prosthesis on the X-ray images. It is been widely believed that the teardrop structure serves as a stable anatomical marks, therefore, the bilateral measurements were performed as follows: (1) the height of the acetabular centre H was the vertical distance from the centre of the cup prosthesis or acetabulum to the bilateral inter-teardrop line, and (2) the horizontal location of the acetabular centre W was the horizontal distance from the centre of the cup prosthesis or acetabulum to the vertical tangent line of the inside edge of the ipsilateral teardrop (Figure 8).

3. Results

During the operation, the optimal fit of the template to the acetabular fossa was easy to obtain in all cases. By direct viewing, we could observe that the surface of the acetabular fossa perfectly matched the template surface without any deviation. The postoperative x-rays and CT images revealed the templates to be accurately placed.

The **results** show that the abduction angle (β) of the cup was ($49.9^\circ \pm 4.1^\circ$) versus ($49.5^\circ \pm 4.7^\circ$) on the contralateral side. The anteversion angle (α) of the cup was ($17.7^\circ \pm 3.1^\circ$) versus ($18.3^\circ \pm 3.5^\circ$) on the contralateral side (Figures 9 and 10). In the operative hip, the height of the prosthesis centre H was ($21.6 \text{ mm} \pm 2.8 \text{ mm}$) versus ($21.9 \text{ mm} \pm 3.4 \text{ mm}$) on the contralateral side, and the horizontal location of the prosthesis centre W was ($29.7 \text{ mm} \pm 3.1 \text{ mm}$) versus ($30.90 \text{ mm} \pm 3.31 \text{ mm}$) in the contralateral side (Figure 11).

There was no significant difference in the cup abduction (β) or anteversion (α) angle between the operative and contralateral sides ($P = 0.7531 > 0.05$ for (β) and $P = 0.5996 > 0.05$ for (α)); In addition, there was no significant difference in the height H or horizontal location W of the acetabular centre between the operative and contralateral sides ($P = 0.6494 > 0.05$ for (W) and $P = 0.5143 > 0.05$ for (H)).

4. Discussion

THA is one of the most conventional orthopaedic reconstructive procedures. Significant improvement in functional outcomes and prosthesis survival have been achieved due to the advances in surgical techniques and bioengineering technology [8–11]. However, the long-term survival of prostheses and the occurrence of postoperative complications remain challenges in THA [12]. Research indicates that the survival rate of the femoral component is higher than that of the acetabular component [13], and the prosthesis lifespan mainly relies on the survival of the acetabular component in THA. Therefore, the orientation of the acetabular cup has a significant effect on the long-term outcome of THA.

Traditionally, depending on a surgeon's subjective decision and experience, the acetabular cup is inserted within the range of the "safety zone" intraoperatively [14–18]; it is acceptable that an acetabular prosthesis is inserted with an abduction angle ranging from 40° to 60° and an anteversion angle ranging from 5° to 25° [19]. However, this approach not always results in accurate placement. The computer navigation system optimizes the implantation of prosthesis [18], but it can be easily influenced by the pelvic position [20], which results in a combination of errors in registration, landmark identification, and device tracking [21]. The cost of navigation system must also be taken into consideration.

Generally, the orientation of the cup is determined based on its anteversion and abduction. In 3D space, the acetabular central axis indicates the opening orientation of the acetabulum. The central axis of the acetabular prosthesis should coincide with the anatomical acetabular central axis. Thus, the physiological and biomechanical environment of the hip joint can be restored optimally. Therefore, determining the acetabular centre of rotation and the central axis is the basis of biomechanical restoration in THA.

In general, it is difficult to locate the central axis during the operation because of variations in the center of the acetabulum due to osteoarthritis. However, it was easy for the “mirror image” of the normal side to serve as a reference in this study. In this case, we obtained the rotational centre of the contralateral side, which could then be considered as the centre of the diseased side. Using the anatomical landmarks for the measurements which can be clearly marked on the projections of the pelvis, the anteversion and abduction angles can be obtained, and errors can be minimized.

In this study, the coordinates of the acetabular central axis were determined by two points, one point being the centre of the contralateral acetabulum, and the other point being point “L”, which was calculated using trigonometric function named after the senior author LJL. Point “L” is a unique point related to the radius of the contralateral acetabulum, it is located on the acetabular central axis and can be seen as a site spatially transferred from the centre of the acetabulum. By constructing an appropriate reference frame, we can easily calculate the spatial straight-line equation of the acetabular central axis and the coordinates of point “L” .

We chose the acetabular fossa as the reference for the navigation template because it has many advantages, such as little variation in shape, no articular cartilage covering the surface, and stable and unique bony features. Therefore, an accurate fit can be achieved. We could also simulate the postoperative view using software and assess the location of the prosthesis and the validity of the navigational template.

Therefore, our patient-specific navigational template is easy to apply intraoperatively without much special training or a steep learning curve, in contrast with complex computer navigation systems. This template can meet the needs of different individuals and decreases the duration of operation. The time required for design and manufacturing, as well as the cost, are acceptable for most patients. Therefore, our template is a simple and low-cost solution that can be precisely, safely, and rapidly implemented in unilateral THA.

Certainly, there are several limitations to this research. First, in the case of deformity on the contralateral side, e.g. that in pathological conditions such as dysplasia and post-traumatic malunion, among others, the method we propose may not be very effective. Severe dysplasia and osteoarthritis on the operation side, which may lead to a deformed acetabular fossa, can also cause inaccurate placement of the acetabular cup. Second, this was a cadaveric study, and the proposed method has not been applied in clinical practice. Furthermore, 20 is a small number compared with the number of THA surgeries every year, thus, the results may not represent the various abnormalities in such a population. Third, errors in the designing and RP procedures are inevitable, and the symmetry of bilateral acetabular fossae of bilateral sides needs to be further researched.

5. Conclusion

In this study, we introduced a novel patient-specific navigational template, for assisting in accurate acetabular prosthesis placement in a unilateral THA. The orientation of acetabular prosthesis can be

determined by mirrored the normal side. This approach enables an accurate fit to be achieved between the navigational template and the operative site, thereby allowing guided intra-operative placement of the acetabular cup. The affordable template can effectively guide acetabular cup placement.

Abbreviations

THA:Total Hip Arthroplasty; CT:Computed tomography; RP:Rapid prototyping; DICOM:Digital imaging and communications in medicine; STL:Stereolithograph; CAD/CAM:Computer-aided manufacturing; RP&CAE: Computer-aided engineering;

Declarations

The need for ethics approval was deemed unnecessary for this cadaver research by the Ethics Committee of 920th Hospital of Joint Logistics Support Force.

We all agree to publish this article if it is accepted.

All the data are authentic and reliable.

The authors declare that there has no competing interests as defined by Nature Research, or other interests that might be perceived to influence the results and/or discussion reported in this paper, and there has no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

This study is supported by the China Natural Science Foundation (Grant No. 2017ZF025).

In this study, JL Liang, YQ Xu, and S Lu conceived the study. JL Liang wrote the manuscript text. YH Zhao collected data. XJ Gao, XW Fang analyzed results. JL Liang, YH Zhao and S Lu performed Cadaveric Study, YQ Xu, S Lu technical support. All authors reviewed the manuscript.

References

1. Theis M. Thilemann, Alma B. Pedersen, Frank Mehnert, Sren P. Johnsen, Kjeld Sballle. Postoperative use of bisphosphonates and risk of revision after primary total hip arthroplasty: A nationwide population-based study. Bone. 2010 ;46; 946-951.
2. Xavier Flecher, Sebastien Parratte, Nicolas Brassart, Jean-Manuel Aubanian, Jean-Noel Argenson. Evluation of the Hip Center in Total Hip Arthroplasty for Old Developmental Dysplasia. The Journal of Arthroplasty . 2008; 23 No. 8.
3. Crowninshield, R.D, Rosenberg, A.G, Sporer, S.M. Changing demographics of patients with total joint replacement. Clin Orthop Relat. Res. 2006;443, 266–272.
4. Bin CHEN, Sheng-xiang XIAO, Peng-cheng GU, Xiang-jin LIN. Personalized image-based templates for precise acetabular prosthesis placement in total hip arthroplasty: a pilot study. Journal of ZheJiang

University-SCIENCE B (Biomedicine& Biotechnology) 2010;11 (9): 673-680.

5. AlexandreJourne, JeromeSadaka, ClaireBelicourt, AlainSauter. New method for measuring acetabular component positioning with EOS imaging: feasibility study on dry bone. International Orthopaedics (SICOT). 2012;36:2205-2209.
6. Bicanic G, Delimar D, Delimar M, Pecina M. Influence of the acetabular cup position on hip load during athroplasty in hip dysplasia. Int Orthop 2009;33(2):397-402
7. D'LimaDD, UrquhartAG, BuehlerKO, WalkerRH, Colwell CW Jr. The effect of the orientation of the acetabular and femoral components on the range of motion of the hip at different head-neck ratios. J Bone Joint Surg Am. 2000;82(3):315-321
8. Bourne RB, Maloney WJ, Wright JG. An AOA criticalissue. The outcome of the outcomes movement. J Bone Joint Surg Am. 2004;86:633-40.
9. Diana Glaser a, Douglas A. Dennis a, b, Richard D. In vivo comparison of hip mechanics for minimally invasive versus traditional total hip arthroplasty. Clinical Biomechanics 2008;23;127–134
10. James L. Howard, HilalMaraditKremers, Youlonda A. loechler, etal, Comparative Survival of Uncemented Acetabular Components Following Primary Total Hip Arthroplasty. J Bone Joint Surg Am. 2011; 93: 1597-604.
11. Michael H. Huo, Kristopher G. Stockton, Michael A. Mont, Robert W. Bucholaz. What's New in Total Hip Arthroplasty. J Bone joint Surg Am. 2010; 94: 1721-7.
12. By John C. Clohisy, Michael A. Dobson, Jason F. Robison. Radiographic Structural Abnormalities Associated with Premature, Natural Hip-Joint Failure. J Bone Joint Surg Am. 2011;93;3~9
13. Kawamura K, Dunbar M, Pracaic M, et al. The porous coated anatomic total hip replacement: a ten to fourteen-year follow-up study of a cementless total hip arthroplasty. J Bone Joint Surg Am, 2001, 83(9):1333-1338.
14. Conroy JL, Whitehouse SL, Graves SE, Pratt NL, 8Ryan P, Crawford RW. Risk factors for revision for earlydislocation in total hip arthroplasty. J Arthroplasty.2008;23:867-72.
15. Joseph M, Susan C. Improving the accuracy of acetabular component orientation: avoiding malposition. J Am AcadOrthoSurg, 2010;18:286-296.
16. Rousseau MA, Lazennec JY, Boyer P, Mora N, Gorin M, Catonné Y. Optimization of total hip arthroplasty implantation: is the anterior pelvic plane concept valid? J Arthroplasty. 2009; 24(1):22-26.
17. Archbold HA, Mockford B, Molloy D, McConway J, Ogonda L, Beverland D. The transverse acetabular ligament: an aid to orientation of the acetabular component during primary total hip replacement. J Bone Joint Surg Br. 2006; 88(7):883-886.
18. Michael J. Seel, Mahmoud A. Hafez, FRCS(Ed), et al. Three-dimensional Planning and Virtual Radiographs in Revision Total Hip Arthroplasty for Instability. Clinical Orthopaedics and Related Research. January 2006 ; 442, pp. 35–38.

19. Muller O, Reize P, Trappmann D, Wulker N. Measuring anatomical acetabular cup orientation with a new X-ray technique. *Aided Surg.* 2006;11(2):69-75. [doi:10.1080/10929080600640618]
20. Parratte S, Pagnano MW, Coleman-Wood K, Kaufman KR, Berry DJ. The 2008 Frank Stinchfield award: variation in postoperative pelvic tilt may confound the accuracy of hip navigation systems. *ClinOrthopRelat Res.* 2009; 467(1):43-49.
21. Lawrence D. Dorr, Aamer Malik, Zhinian Wan, William T. Long, Michael Harris. Precision and Bias of Imageless Computer Navigation and Surgeon Estimates for Acetabular Component Positon. *ClinOthropRelat Res.* 2007; 465: 92-99.

Figures

Figure 1

A suitable sphere was fitted to the point cloud of the contralateral acetabulum. Error analysis can be performed: the red areas indicated less mean the fitting precision has a relatively large deviation, the green and yellow areas indicate less fitting deviation, and the blue areas indicate negative deviation.

Figure 2

Schematic of the anteversion and abduction angles. (A) The abduction angle (β) was the acute angle between the line connecting the bilateral acetabular centre of rotation and the long axis of the two edges of the projected shadow of the acetabulum on the coronary section. (B) The anteversion angle (α) was the complement angle between the two connecting lines described above on the transverse section.

Figure 4

The virtual patient-specific navigational template. (A) The virtual surface of the template matched the surface of the acetabular fossa perfectly. (B) The shape of the navigational template from different visual perspectives.

Figure 5

Cadaveric experiment. (A) Exposure of the acetabular fossa. (B) Matching the navigational template to the surface of the acetabular fossa. (C) Insertion of the guide pin along the guidance channel. (D) Implantation of an acetabular cup.

Figure 6

The modified acetabular reamer we used.

Figure 7

Postoperative CT images and the measurements of the anteversion (α) and the abduction(β) angles of the cup prosthesis. The figure clearly reveal the exact location of the cup prosthesis on different pelvic spatial planes.

Figure 8

Postoperative X-ray images showing that the guide pin is perpendicular to the opening plane of the cup and coincidence with the acetabular central axis practically, The figure also shows the measurement method of the height H and the horizontal location W of the prosthesis centre.

Figure 9

The average angle of abduction(β). Data are expressed as mean $\pm$ SD. There is no significant difference between the operative side and contralateral sides ($P=0.7531 > 0.05$).

Figure 10

The average angle of anteversion(α). Data are expressed as the mean $\pm$ SD. There was no significant difference between the operative and contralateral sides ($P=0.5996 \geq 0.05$).

Figure 11

The height H and the horizontal location W of the acetabular center. Data are expressed as mean $\pm$ SD. There is no significant difference between the operative side and the contralateral side ($P \geq 0.05$).