Original Article

The effect of c-arm tilt on accuracy of intraoperative fluoroscopy in assessing acetabular component position during direct anterior approach for hip arthroplasty

Eugene S. Jang*, James D. Lin, Roshan P. Shah, Jeffrey A. Geller, H. John Cooper

Department of Orthopaedic Surgery, Columbia University Medical Center, 622 West 168th Street, New York, NY 10032, United States

ARTICLE INFO

Keywords:

Total hip arthroplasty
Direct anterior approach
Fluoroscopy
Pelvic tilt
Anteversion
Inclination

ABSTRACT

Intraoperative fluoroscopy can improve the precision of acetabular component positioning during direct anterior hip arthroplasty. However, changes in pelvic tilt with c-arm positioning may compromise accuracy. A geometric model of an acetabular component's projection onto fluoroscopy images was created and manipulated to simulate c-arm tilt. An apparently ideally-placed cup will have its effective anteversion changed by 7.5° with just 10° of caudal/cephalad tilt of the c-arm. This effect is greater in cups that are more horizontally placed or less anteverted. Accurate c-arm positioning is crucial, as small errors in tilt can have considerable effects on final cup position.

1. Introduction

The direct anterior approach to the hip is an increasingly common technique in total hip arthroplasty. Early clinical results suggest that the direct anterior approach results in shorter length of stay, improved early postoperative pain and function, and more rapid weaning of walking aids. There is controversy over the incidence of postoperative instability and other complications in anterior versus posterior approach, but a large-scale meta-analysis did not demonstrate clear superiority of either approach.¹

One of the advantages of using a direct anterior approach is that it may be performed in a supine position, facilitating real-time fluoroscopic assessment of the position of the acetabular component during reaming and implant placement. The use of fluoroscopy can offer a degree of precision in terms of cup positioning that is unavailable to the surgeon relying on physical landmarks.²

One underappreciated pitfall with intraoperative fluoroscopy is how much the tilt of the c-arm or pelvis in the sagittal plane can affect the perceived positioning of the acetabular component. A fluoroscope that is vertically oriented with respect to the operating room floor may not correspond with a true standing anteroposterior (AP) view of the pelvis, and in reality be more of an inlet or outlet view. Subtle intraoperative errors in positioning of the patient, the operating room table, or the c-arm may have large effects on the eventual functional component position. A better understanding of how c-arm positioning affects cup

position would help surgeons recognize and prevent these issues.

The purpose of this study was to derive a mathematical model of how the degree of c-arm tilt in a sagittal plane can create a mismatch between the true position of a cup and its radiographic appearance on fluoroscopy, and translate this derivation to a clinically relevant correlative model. A better understanding of this effect should help surgeons to recognize when they are in danger of malpositioning the acetabular component.

2. Methods

Models were constructed of an acetabular component in a 3-dimensional space in relation to a patient supine on an operating room table (Fig. 1). The true amount of anteversion and inclination of the cup were defined as A_T and I_T , respectively. A normal vector n orthogonal to the acetabular component (i.e. the direction of the reamer) may then be defined in terms of true inclination and true anteversion:

$$\text{Let } n = \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} \cos(A_T)\sin(I_T) \\ \cos(A_T)\cos(I_T) \\ \sin(A_T) \end{pmatrix} \quad (1)$$

When a c-arm is malpositioned by a certain degree Θ , a new normal vector n' is created:

* Corresponding author.

E-mail addresses: ej2226@cumc.columbia.edu (E.S. Jang), jdl2161@cumc.columbia.edu (J.D. Lin), rs3464@cumc.columbia.edu (R.P. Shah), jg2520@cumc.columbia.edu (J.A. Geller), hjc2008@cumc.columbia.edu (H.J. Cooper).

<https://doi.org/10.1016/j.jor.2018.03.036>

Received 1 December 2017; Accepted 25 March 2018

Available online 27 March 2018

0972-978X/ © 2018 Prof. PK Surendran Memorial Education Foundation. Published by Elsevier, a division of RELX India, Pvt. Ltd. All rights reserved.

deconstructed to x' , y' , and z' components.

$$\begin{aligned} n' &= \begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = A \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(\theta) & \sin(\theta) \\ 0 & -\sin(\theta) & \cos(\theta) \end{pmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} x \\ y\cos(\theta) + z\sin(\theta) \\ z\cos(\theta) - y\sin(\theta) \end{pmatrix} \\ &= \begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} \end{aligned} \quad (2)$$

The values of the distances x' , y' , and z' define the degree of perceived anteversion and inclination (A_P and I_P) that is apparent through the (now-malpositioned) c-arm.

$$\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = \begin{pmatrix} \cos(A_P)\sin(I_P) \\ \cos(A_P)\cos(I_P) \\ \sin(A_P) \end{pmatrix} \quad (3)$$

$$\begin{aligned} x' &= x = \cos(A_T)\sin(I_T) \\ y' &= y\cos(\theta) + z\sin(\theta) = \cos(A_T)\cos(I_T)\cos(\theta) + \sin(A_T)\sin(\theta) \\ z' &= z\cos(\theta) - y\sin(\theta) = \sin(A_T)\cos(\theta) - \cos(A_T)\cos(I_T)\sin(\theta) \end{aligned} \quad (4)$$

Combining Formulas (3) and (4) above yields:

$$\begin{aligned} x' &= \cos(A_P)\sin(I_P) \\ y' &= \cos(A_T)\cos(I_T)\cos(\theta) + \sin(A_T)\sin(\theta) = \cos(A_P)\cos(I_P) \\ z' &= \sin(A_T)\cos(\theta) - \cos(A_T)\cos(I_T)\sin(\theta) = \sin(A_P) \end{aligned} \quad (5)$$

Using standard trigonometric identity formulas, the equations were derived for perceived anteversion and inclination caused by c-arm error of θ degrees for any amount of true anteversion and inclination:

$$A_P = \arcsin[\sin(A_T)\cos(\theta) - \cos(A_T)\cos(I_T)\sin(\theta)] \quad (6)$$

$$I_P = \operatorname{arccot}\left[\cot(I_T)\cos(\theta) + \frac{\tan(A_T)}{\sin(I_T)}\sin(\theta)\right] \quad (7)$$

This equation is consistent with a previously published derivation examining a similar problem (resting cup position as a function of pelvic tilt).³ Representative values produced by this formula on a cup positioned in 40° of inclination and 15° of anteversion are presented in Table 1.

3. Discussion

At our institution, it is routine to begin the fluoroscopic assessment of the patient with an AP image centered on the pelvis. This is followed immediately by an adjustment of c-arm sagittal tilt to match the patient's preoperative standing pelvic radiograph. This step ensures that the apparent position of the cup on intraoperative fluoroscopy will match the eventual position of the cup when the patient stands, rather than assuming that the c-arm being vertical while the patient is supine represents a true AP.

Our model demonstrates that this step of matching the tilt of intraoperative fluoroscopy to preop x-ray is one that merits careful

Fig. 1. Illustration of spatial variables in relation to clinical scenario. Figure demonstrating relationship between the spatial variables and clinical scenario of a patient supine on an operating room table. θ indicates the degree of c-arm tilt in the sagittal plane, with positive values corresponding to a progression towards an inlet view, and negative values, an outlet view. The x -, y -, and z -axis vectors are defined as being parallel to the sagittal, axial, and coronal planes, respectively. A unit vector $\hat{n}$ may be defined as the vector orthogonal to the face of the acetabular component, corresponding with the position of a standard reamer or impactor, whereby $\hat{n} = \begin{pmatrix} x \\ y \\ z \end{pmatrix}$. A_T and I_T correspond to the true anteversion and inclination of the cup. A_P and I_P correspond to the perceived anteversion and inclination of the cup that is apparent through a c-arm that is malpositioned, which define a new unit vector $\hat{n}'$ which can be

Table 1

Relationship between true anteversion/inclination of acetabular cup, and perceived anteversion/inclination on intraoperative fluoroscopy, as a function of c-arm tilt, for selected values.

Perceived Cup Anteversion (A_P)	Perceived Cup Inclination (I_P)	Relative C-arm tilt (θ)	True Cup Anteversion (A_T)	True Cup Inclination (I_T)
15	40	20	-0.6	38.4
15	40	15	3.4	38.5
15	40	10	7.3	38.7
15	40	5	11.1	39.3
15	40	0	15.0	40.0
15	40	-5	18.8	41.0
15	40	-10	22.5	42.2
15	40	-15	26.2	43.8
15	40	-20	29.8	45.7
15	30	10	6.3	29.1
15	30	-10	23.6	31.8
5	40	10	-3.7	29.9
5	40	-10	13.6	30.8

All numbers represented in degrees (°). C-arm tilt: positive values = degrees of inlet view, negative values = degrees of outlet view, 0° = orthogonal to coronal plane of patient. Note that in an ideally placed cup, each 10° of c-arm tilt $\approx$ 7.5° of error in anteversion, but only $\approx$ 2° of error in inclination. If cups are placed more horizontally (e.g. 30° inclination), this effect is increased to 10° of c-arm tilt $\approx$ 9° of anteversion. With less anteversion (e.g. 5°), the effect is similarly increased to 10° tilt $\approx$ 9° of anteversion.

attention. Assuming an acetabular component is ideally positioned in 40° inclination and 15° anteversion, having the c-arm differ from pre-operative radiographs by only 10° in a caudal/cephalad direction will result in a change in anteversion of approximately 7.5° (true anteversion of 7.3 or 22.5°, respectively) (Table 1). The inclination only changes by $\approx$ 2° with this amount of c-arm tilt. This effect becomes more pronounced in more horizontally placed components; those with 30° of inclination will have their anteversion changed by almost 9° for every 10° of c-arm tilt. The same holds true for less anteverted cups.

An understanding of the geometric relationship between c-arm position and the location of the pelvis in space can also be used to the surgeon's advantage when dealing with patients with abnormal pelvic tilt, which can affect functional component position.⁴ Patients with abnormal sagittal balance in the lumbar spine, or those status post spinal fusion surgeries, may have obligate pelvic malpositioning when on the operating room table. The understanding of how abnormal spinopelvic parameters affects cup positioning is rapidly expanding.⁵ The simple, fast, and cost-effective step of adjusting c-arm tilt has the potential to mitigate some of the effects of abnormal pelvic tilt or spinal fusion on cup positioning.

A heightened awareness of the importance of c-arm tilt, and an

understanding of why it has such a significant effect on final cup positioning, may serve as an important tool in the armamentarium of a surgeon performing direct anterior hip arthroplasty to ensure more consistent outcomes and reduced complication rates. This rule of thumb of “10° c-arm tilt equals 7.5° anteversion change” should be a useful guide in accounting for differences between preoperative and intraoperative imaging.

Conflicts of interest

Dr. Cooper reports and paid consultant for Corin, KCI, and Zimmer-Biomet; however, the submitted work describes a technique/presents a mathematical model, does not mention or endorse any specific products.

Dr. Geller reports and paid consultant for Smith & Nephew and Biosensor; however, the submitted work describes a technique/presents a mathematical model, does not mention or endorse any specific products.

Dr. Jang has nothing to disclose.

Dr. Lin has nothing to disclose.

Dr. Shah reports and paid consultant for Link Bio; however, the submitted work describes a technique/presents a mathematical model, does not mention or endorse any specific products.

References

1. Higgins BT, Barlow DR, Heagerty NE, Lin TJ. Anterior vs. posterior approach for total hip arthroplasty, a systematic review and meta-analysis. *J Arthroplasty*. 2015;30(3):419–434. <http://dx.doi.org/10.1016/j.arth.2014.10.020>.
2. Rathod PA, Bhalla S, Deshmukh AJ, Rodriguez JA. Does fluoroscopy with anterior hip arthroplasty decrease acetabular cup variability compared with a nonguided posterior approach? *Clin Orthop Relat Res*. 2014;472(6):1877–1885. <http://dx.doi.org/10.1007/s11999-014-3512-2>.
3. Lembeck B, Mueller O, Reize P, Wuelker N. Pelvic tilt makes acetabular cup navigation inaccurate. *Acta Orthop*. 2005;76(4):517–523. <http://dx.doi.org/10.1080/17453670510041501>.
4. Maratt JD, Esposito CI, McLawhorn AS, Jerabek SA, Padgett DE, Mayman DJ. Pelvic tilt in patients undergoing total hip arthroplasty: when does it matter? *J Arthroplasty*. 2015;30(3):387–391. <http://dx.doi.org/10.1016/j.arth.2014.10.014>.
- [5]. Buckland AJ, Vigdorchik J, Schwab FJ, et al. Acetabular anteversion changes due to spinal deformity correction: bridging the gap between hip and spine surgeons. *J Bone Jt Surg Am*. 2015;97(23):1913–1920. <http://dx.doi.org/10.2106/JBJS.O.00276>.