Rotation effect and anatomic landmark accuracy for midline placement of lumbar artificial disc under fluoroscopy

Mark Mikhael, Jaysson T. Brooks, Yusuf T. Akpolat & Wayne K. Cheng

European Spine Journal

ISSN 0940-6719

Eur Spine J
DOI 10.1007/s00586-015-3990-2

Springer

Eur Spine J
DOI 10.1007/s00586-015-3990-2

ORIGINAL ARTICLE

Rotation effect and anatomic landmark accuracy for midline placement of lumbar artificial disc under fluoroscopy

Mark Mikhael[1] · Jaysson T. Brooks[2] · Yusuf T. Akpolat[1] · Wayne K. Cheng[1]

Received: 7 January 2015 / Revised: 1 May 2015 / Accepted: 2 May 2015

Abstract
Purpose Total disc arthroplasty can be a viable alternative to fusion for degenerative disc disease of the lumbar spine. The correct placement of the prosthesis within 3 mm from midline is critical for optimal function. Intra-operative radiographic error could lead to malposition of the prosthesis. The objective of this study was first to measure the effect of fluoroscopy angle on the placement of prosthesis under fluoroscopy. Secondly, determine the visual accuracy of the placement of artificial discs using different anatomical landmarks (pedicle, waist, endplate, spinous process) under fluoroscopy.
Methods Artificial discs were implanted into three cadaver specimens at L2-3, L3-4, and L4-L5. Fluoroscopic images were obtained at 0°, 2.5°, 5°, 7.5°, 10°, and 15° from the mid axis. Computerized tomography (CT) scans were obtained after the procedure. Distances were measured from each of the anatomic landmarks to the center of the implant on both fluoroscopy and CT. The difference between fluoroscopy and CT scans was compared to evaluate the position of prosthesis to each anatomic landmark at different angles.
Results The differences between the fluoroscopy to CT measurements from the implant to pedicle was 1.31 mm, $p < 0.01$; implant to waist was 1.72 mm, $p < 0.01$; implant to endplate was 1.99 mm, $p < 0.01$; implant to spinous process was 3.14 mm, $p < 0.01$. When the fluoroscopy angle was greater than 7.5°, the difference between fluoroscopy and CT measurements was greater than 3 mm for all landmarks.
Conclusions A fluoroscopy angle of 7.5° or more can lead to implant malposition greater than 3 mm. The pedicle is the most accurate of the anatomic landmarks studied for placement of total artificial discs in the lumbar spine.

Keywords Artificial disc · Total disc replacement · Malposition · Fluoroscopic guidance · Accuracy

Introduction

Proper placement of the lumbar artificial disc is critical to ensure optimal outcomes and device functionality [1]. It was shown that disc malposition predisposes to asymmetric loading, implant wear, implant loosening, and non-physiological stresses on adjacent vertebral segments in clinical and biomechanical studies [2–5]. Ideal placement is poorly defined, however, manufacturers of the Charitè implant define it as less than 3 mm from the midline. McAfee et al. [1, 6] divide radiographic placements into 3 subcategories correlated with clinical outcomes: optimal (within 3 mm of axis), suboptimal (3–5 mm) and poor placement (>5 mm). In one biomechanical study, 3 mm was stated as a common inclination [7].

Current practice is to place these implants in the operating room under fluoroscopic guidance. Although using computerized tomography (CT) intraoperatively would be most ideal, it is not practical. A study by Mistry et al. [8] showed that the interpedicular midpoint in comparison to the vertebral body and spinous process is the most accurate guide to the coronal midline on CT. However, the question

✉ Wayne K. Cheng
md4spine@yahoo.com

1 Department of Orthopaedic Surgery, School of Medicine, Loma Linda University, 11406 Loma Linda Dr, Suite 213, Loma Linda, CA 92354, USA

2 Department of Orthopedic Surgery, Johns Hopkins Hospital, Baltimore, MD, USA

Published online: 14 May 2015

remains as to which anatomic landmarks could be used during fluoroscopy that would achieve the closest accuracy to CT.

There are reports of prosthesis malpositions [5, 9–11]. The causes of malpositions generally were divided as a short term (within 1 week) and as a long term (after 1 week). Short term reasons are dislocation, oversizing, and not correctly locked prosthesis. Long term reasons are subluxation, slow anterior migration, degenerative disease at another level, facet joint arthrosis, and trauma. In addition, in the operating rooms there are conditions that affect the patient's body position and fluoroscopy machine position. Use of a C-arm could cause such false positioning (due to the parallax effect) [12, 13].

There have been no prior studies that have compared the effect of angle rotation while placing artificial disc under fluoroscopy to CT and no prior studies to determine which anatomic landmark is most accurate to place the prosthesis in the midline position. The purpose of this study was first to determine how the rotation affects the midline placement of artificial disc under fluoroscopy. Secondly, to determine the most accurate anatomic landmark to place a total disc prosthesis using fluoroscopy compared to CT.

Materials and methods

Implant used in this study was the Charitè III artificial disc (DePuy Spine, Raynham, MA). Three cadavers were obtained. Levels used were L2-3, L3-4, and L4-L5. These disc spaces were dissected and prepared for the placement of implants. Implants were placed at the aforementioned levels. Nine implants were placed, three per cadavers. They were implanted in simulating operating room conditions.

After implant placements, fluoroscopy (OEC Fluorostar 9800, GE Medical System, Fairfield, CT) images were obtained for each levels at 0°, 2.5°, 5°, 7.5°, 10°, and 15° from the mid axis by rotating the fluoroscopy machine. The cadavers were placed on the operating table, pelvis was tapped down to minimize potential movement. CT (Light Speed 16 Multi Detector, GE Medical System, Fairfield, CT) scans were then taken of the cadavers with the implants in place. Coronal and sagittal reconstructions were also obtained.

Using the tools on the image viewing software (AGFA Healthcare, Greenville, SC), measurements were recorded from the midline of the implant to each of the designated anatomic landmarks: the medial border of the pedicles, the most medial point of the vertebral body waists, the vertebral endplates, and the spinous processes. This was done by using a marker to draw the axis of the center of the implant and measuring the distance from each of the landmarks to the center line (Fig. 1). The Charitè disc implant has two rows of three keels that were used to estimate the center of the implant. The same measurements were then taken on the CT images of the cadavers (Fig. 2). Measurements were obtained by two different interpreters.

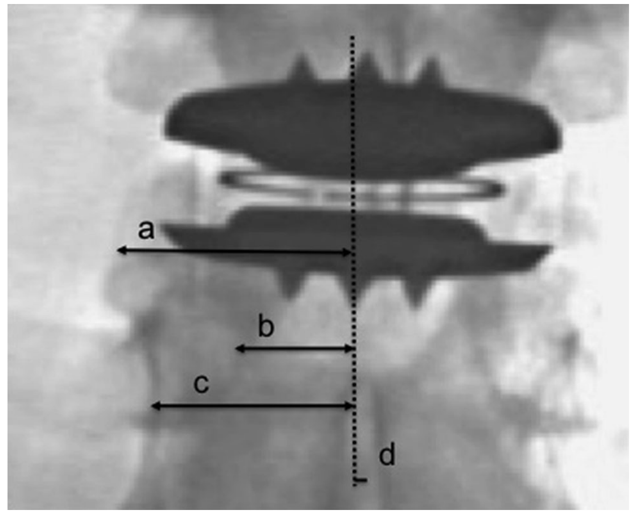

Fig. 1 Measurements from midline to anatomical landmarks on fluoroscopic image. **a** Vertebral endplates, **b** medial border of the pedicles, **c** most medial point of the vertebral body waists, and **d** spinous processes

After measurements were obtained on the fluoroscopic images and the CT scans, data were analyzed. We designated the measurements obtained on the CT scans as the gold standard. The mean differences in the measurements between each of the fluoroscopic images at the various angles were then compared to CT. The landmarks whose measurements on fluoroscopy were closest to those on CT were determined to be the most accurate when assessing the midline of the implant.

The mean, standard deviations, and paired *t* tests were calculated for each anatomic landmark.

Results

The centered position of prosthesis appears to be progressively deviated to one side as the fluoroscopic image rotates from 0° to 15° (Fig. 3).

In one cadaver, implant placed in L2-3 was not included in the study because of the endplate breach. So data were analyzed from eight disc placements.

The mean difference in distance on fluoroscopy at 0° when compared to CT from the pedicle, vertebral body waist, vertebral body endplate, and spinous process to the center of the implant was 1.31, 1.72, 1.99, and 3.14 mm, respectively. The difference in the measurements from the medial border of the pedicle to the midline of the implant when comparing fluoroscopy to CT was statistically

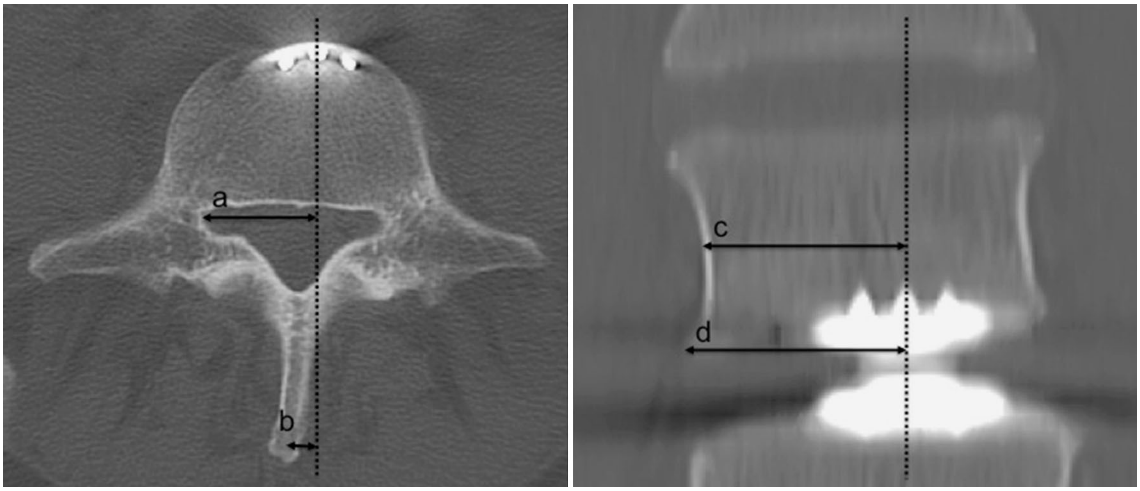

Fig. 2 Measurements from midline to anatomical landmarks on CT image. **a** Medial border of the pedicles, **b** spinous processes, **c** most medial point of the vertebral body waists, and **d** vertebral endplates

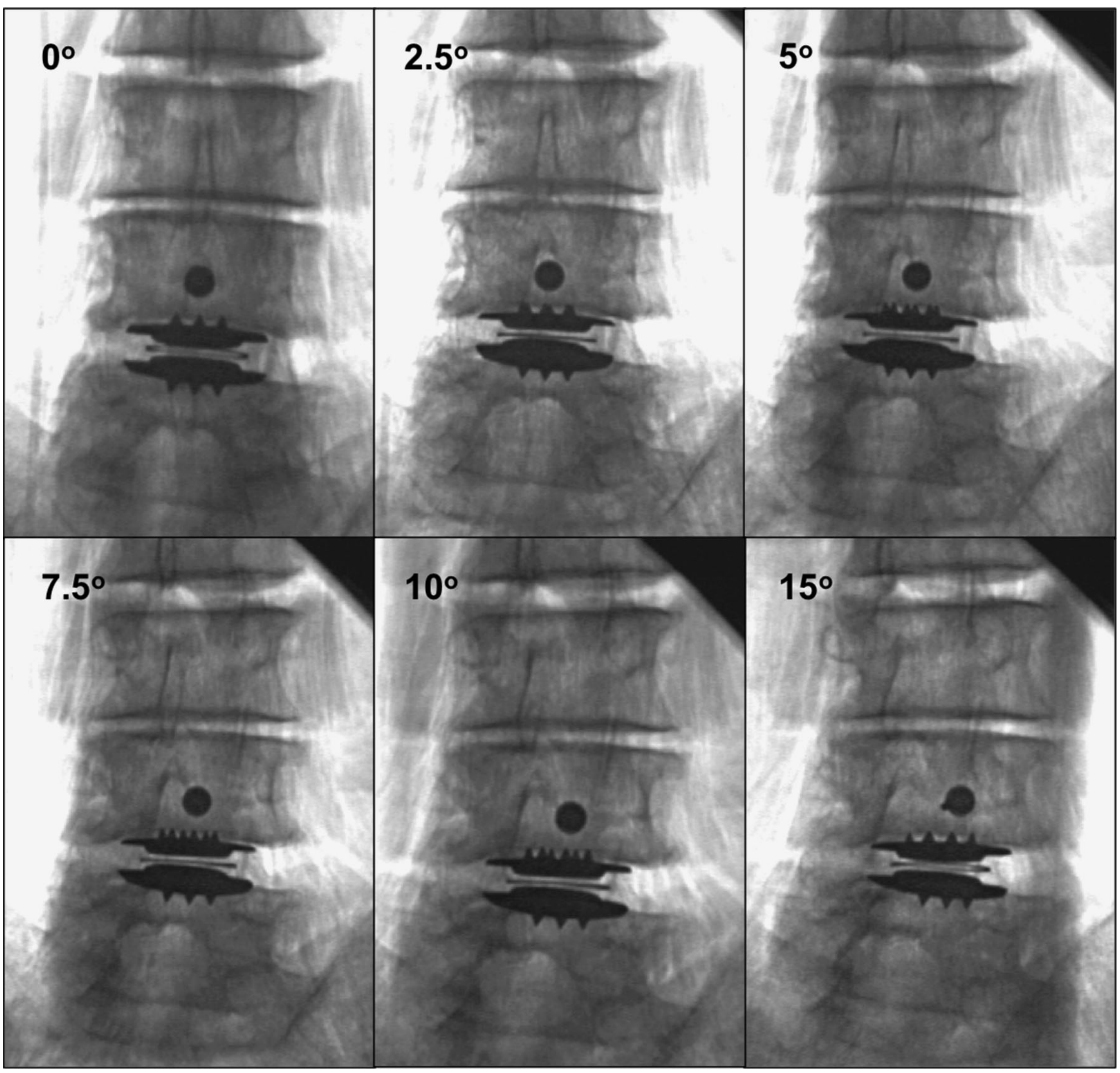

Fig. 3 Six fluoroscopic images when the fluoroscopy was angled at 0°, 2.5°, 5°, 7.5°, 10°, and 15°

Table 1 Mean differences between CT and fluoroscopy for anatomic landmarks with different angles

Mean difference (in mm)				
Degrees	Pedicle	Waist	Endplate	Spinous process
0°	1.31	1.72	1.99	**3.14**
SD	0.92	1.38	1.43	2.43
p	<0.01	<0.01	<0.01	<0.01
2.5°	1.92	2.45	2.92	**3.68**
SD	0.86	1.40	1.63	3.55
p	0	0	<0.01	<0.01
5°	2.63	**3.07**	**3.62**	**4.29**
SD	1.38	1.48	1.50	2.73
p	<0.01	0	0	<0.01
7.5°	**3.09**	**3.58**	**4.47**	**4.75**
SD	1.22	1.72	1.70	3.28
p	0	<0.01	<0.01	0
10°	**3.92**	**4.43**	**5.11**	**5.23**
SD	1.39	1.62	1.50	3.22
p	0	<0.01	0	<0.01
15°	**4.54**	**5.78**	**6.04**	**6.17**
SD	1.36	1.77	1.87	3.35
p	0	0	0	<0.01

Values greater than 3 mm are given in bold

significant ($p < 0.01$). This was true for all of the angles assessed in the axial plane on fluoroscopy (Table 1).

With the fluoroscopy machine angled at greater than 5°, this will alter possible placement of the implant which could lead to significant complications. The difference in the measurement from the pedicle to the midline at an angle of 7.5° and above led to a difference of more than 3 mm from the same measurement on CT for all landmarks tested.

Discussion

With the increase in number of total disc arthroplasties being performed, come questions regarding the most reliable technique of implantation. Midline placement is important for good outcomes. Currently, total disc arthroplasty is being performed under fluoroscopic guidance in the operating room. Error in midline placement of prosthesis due to fluoroscopy has been pointed out by other authors [2]. In addition, anatomic landmarks used while operating varies from surgeon to surgeon. Some use the medial border of the pedicles to estimate the midline while others may use the spinous processes.

Parallax effect is well known to cause potential errors in fluoroscopic imaging. When the fluoroscopy machine was angled greater than 7.5° from the vertical in the axial plane, we obtained a difference of greater than 3 mm in our fluoroscopy measurements from our CT measurements. This difference was noted using the medial border of the pedicle as the landmark. This error becomes more significant when using other landmarks. When the vertebral body waist and endplate were used, greater than 3 mm difference occurred when the fluoroscopy machine was angled just 5° from the vertical. This demonstrates that small variations in the angle of the fluoroscopy machine in the axial plane can lead to significant errors in midline placement of total disc arthroplasty implants.

We chose to vary the fluoroscopic rotation instead of the cadaver position because it was easier and more accurate than changing and securing the cadaveric specimens with each different angle. However, one can assume that malposition of the patient's body on the operating table such as retraction from table retractor may have similar rotational effect as malpositioning of the fluoroscopy.

This study measured the accuracy of visually identifying different anatomic landmarks under fluoroscopy with total disc arthroplasty implants in place. Our results demonstrated that the use of the medial border of the pedicle to estimate the midline of the intervertebral disc on fluoroscopy was the most accurate method followed by the vertebral waist, vertebral body endplate. Spinous process was the least accurate landmark to be used. It was also noted during the measurement process that vertebral body endplates were easy to be identified on fluoroscopic images. But the presence of osteophytes made endplates difficult to measure and potentially made this landmark less accurate when compared to CT.

Our study results did correlate with Mistry's study that demonstrated that the interpedicular midpoint is the most accurate guide to the coronal midline of the intervertebral disc on CT scan. The methods by which our study and Mistry's study arrived at this conclusion were completely different. In their study, they used only CT scans without any implants in disc spaces. Our study was a fluoroscopy-based study that simulating real operating condition and then fluoroscopic data compared with CT data. We obtained the midline of prosthesis-anatomic landmark distances and calculated the differences between fluoroscopy and CT. In this way, we identified the most accurate anatomic landmark while using fluoroscopy compared to CT.

There is newer method for placing artificial lumbar disc compared to fluoroscopy called surgical freehand navigation systems [12]. In their clinical study, they claim that using navigation systems offers surgeons to avoid the parallax effect and avoid the additional inaccuracy associated with use of the C-arm [14]. These systems have higher prices than traditional fluoroscopy and not affordable for every hospital.

A potential algorithm to insure midline placement of TDR can be developed based on some of the data from this paper:

1. Proper positioning of the patient in the operating room, matching fluoroscopic image to pre-op X-Ray to identify the key anatomic landmarks.
2. It is important to get a true AP using fluoroscopy prior to insertion of TDR. The key landmarks such as pedicles, vertebral body waist, and endplates should be symmetrical to either side of the midline.
3. To insure the proper positioning, surgeons should first look at a distance from midline marker or trial to both sides of the following structures of the caudal vertebra prior to the insertion of prosthesis:
   (a) Medial border of the pedicles
   (b) The most medial point of the vertebral body waist
   (c) The endplates (overhang)
   (d) The spinous process (which is not reliable).
4. The above-mentioned landmarks should be checked again after placement of prosthesis.

There are multiple limitations to this study. Firstly, Charitè prosthesis is no longer available for clinical use; however, we believe that the effect of rotation of fluoroscopy during prosthesis insertion is universal to all prosthesis. Secondly, limited number of cadaver specimens as well as limited levels for each specimen is a major limitation of this study.

In conclusion, change of angle from mid axis of more than 7.5° in axial rotation can lead to significant implant malposition. The pedicle is the most accurate of the anatomic landmarks studied for the placement of total artificial discs in the lumbar spine.

Conflict of interest The authors declare no conflict of interest.

References

1. McAfee PC et al (2005) A prospective, randomized, multicenter Food and Drug Administration investigational device exemption study of lumbar total disc replacement with the CHARITE artificial disc versus lumbar fusion: part II: evaluation of radiographic outcomes and correlation of surgical technique accuracy with clinical outcomes. Spine (Phila Pa 1976) 30(14):576–583 **(discussion E388-90)**
2. Strube P et al (2013) Parameters influencing the outcome after total disc replacement at the lumbosacral junction. Part 2: distraction and posterior translation lead to clinical failure after a mean follow-up of 5 years. Eur Spine J 22(10):2279–2287
3. Rohlmann A et al (2013) Parameters influencing the outcome after total disc replacement at the lumbosacral junction. Part 1: misalignment of the vertebrae adjacent to a total disc replacement affects the facet joint and facet capsule forces in a probabilistic finite element analysis. Eur Spine J 22(10):2271–2278
4. Han KS et al (2013) Effect of centers of rotation on spinal loads and muscle forces in total disk replacement of lumbar spine. Proc Inst Mech Eng H 227(5):543–550
5. Zigler JE, Delamarter RB (2012) Five-year results of the prospective, randomized, multicenter, Food and Drug Administration investigational device exemption study of the ProDisc-L total disc replacement versus circumferential arthrodesis for the treatment of single-level degenerative disc disease. J Neurosurg Spine 17(6):493–501
6. Boss OL et al (2013) Lumbar total disc replacement: correlation of clinical outcome and radiological parameters. Acta Neurochir (Wien) 155(10):1923–1930
7. Rohlmann A et al (2008) Effect of position and height of a mobile core type artificial disc on the biomechanical behaviour of the lumbar spine. Proc Inst Mech Eng H 222(2):229–239
8. Mistry DN, Robertson PA (2006) Radiologic landmark accuracy for optimum coronal placement of total disc arthroplasty in the lumbar spine. J Spinal Disord Tech 19(4):231–236
9. van Ooij A, Oner FC, Verbout AJ (2003) Complications of artificial disc replacement: a report of 27 patients with the SB Charite disc. J Spinal Disord Tech 16(4):369–383
10. David T (2007) Long-term results of one-level lumbar arthroplasty: minimum 10-year follow-up of the CHARITE artificial disc in 106 patients. Spine (Phila Pa 1976) 32(6):661–666
11. Guyer RD et al (2009) Prospective, randomized, multicenter Food and Drug Administration investigational device exemption study of lumbar total disc replacement with the CHARITE artificial disc versus lumbar fusion: five-year follow-up. Spine J 9(5):374–386
12. Kafchitsas K, Rauschmann M (2009) Navigation of artificial disc replacement: evaluation in a cadaver study. Comput Aided Surg 14(1–3):28–36
13. Mathews H, Eisermann L, LeHuec J, Friesem T (2005) Total disc arthroplasty using maverick total disc replacement. In: Guyer R, Zigler J (eds) Spinal arthroplasty: a new era in spine care, Chap 13. Quality Medical Publishing, St. Louis, Missouri
14. Rauschmann MA et al (2009) Insertion of the artificial disc replacement: a cadaver study comparing the conventional surgical technique and the use of a navigation system. Spine (Phila Pa 1976) 34(10):1110–1115