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Comparison of Intraoperative Radiation Exposure for O-Arm Intraoperativect *vs*. C-Arm Image Intensifier in Minimally Invasive Lumbar Fusion

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Abstract

Objective: To evaluate the radiation exposures (RE) to patient and surgeon during minimally invasive lumbar spine surgery with instrumentation under the use of C-arm image intensifier or O-arm intraoperative CT.

Background: Minimally invasive spinal instrumentation is highly dependent on intraoperative imaging because of limited exposure of anatomic landmarks. The choice of imaging tools is important not only for accuracy but also safety. Recently introduced O-arm with navigation is a promising tool that could help to solve many problems encountered with C-arm, but the possible increase in RE is a concern.

Materials and Methods: Twenty-five patients were included in this study; 11 patients who received C-arm assisted surgery (8 PLF, 3 TLIF) and 14 patients who received O-arm assisted lumbar fusion surgery (9 PLF, 5 TLIF). Patients were further divided into three subgroups: TLIF using bilateral mini-Wiltse approach, midline approach TLIF, and midline approach PLF. Surgeon RE was evaluated using a personal finger dosimeter. Patient's exposure was evaluated by an internal dose registration systems of C-arm or O-arm devices respectively and converted into effective dose (ED) using the established tissue weighting factors (WF). The O-arm (CT mode) ED was calculated as Dose Length Product (DLP) x conversion index. The DLP=Computed Tomography Dose Index weighted (CTDIw) x irradiated area (cm2). C-arm ED was calculated as Skin Surface Dose (SSD) (mGy) × WF sum.

Results: The overall mean surgeon RE was 2.19 mSv in C-arm group and 0 mSv in O-arm group (p=0.0003) and the overall mean patient ED was 41.85 mSv in C-arm group and 16.09 in O-arm group (p=0.0004). The value was also lower in each O-arm subgroups when compared to corresponding C-arm subgroups.

Conclusion: We introduced O-arm at our facility to allow the use of precise navigation during surgery. Despite 2 or more CT acquisitions per surgery, the surgeon's RE was completely avoided and patient's RE was reduced to less than a half that of C-arm's, which proves that O-arm is beneficial for both surgeon and patients in MIS lumbar fusion surgery.

Keywords: Radiation exposure; C-arm; O-arm; Minimally invasive spinal instrumentation

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Introduction

Minimally invasive posterior lumbar spine surgery is gaining its popularity. This modification in access strategy minimizes the collateral soft tissue injury. Besides smaller incision and narrower surgical corridor, it also avoids muscle denervation by using known neurovascular and muscular compartment planes. Tendon attachments of paraspinal muscle are also preserved which is important for the dynamic stability of spine [1]. Moreover, reduction of bone and ligament resection also preserved normal spine motion [2]. Because of less soft tissue injury, this results in less post-operative pain, shorter hospital stay, early recovery and may also lead to better long term result. However, anatomical landmarks cannot be fully identified most of the time because of the limited exposure, so intraoperative imaging becomes indispensable for accurate instrumentation.

We have used C-arm as the imaging tool for our surgery but we encountered problems including insufficient quality imaging, only one projection at a time, instrument or other equipment may obscure the view, risk of 'hand on' image which increases the radiation exposure to surgeon's hand and the need to manipulate the C-arm to adjust the angle of projection which is labor consuming. Because of repeated manipulation of the C-arm, it may contaminate the sterile surgical field.

Introduction of the computer assisted surgery (CAS) navigation system with O-arm solved these problems. Besides, it is also useful in revision cases such as complex three-dimensional spine deformities and fused spine in which the bony landmarks cannot be reliably identified. On the other hand, the RE to surgeon and patient remains a concern. In case of exposure the CT mode of O-arm could subject the surgeon and patient to a higher dose of radiation than single snapshot of C-Arm. To clarify this issue, we compared the radiation exposure to the surgeon and patients while using C-arm and O-arm with navigation system for minimally invasive spinal fusion surgery.

Materials and Methods

25 patients (11 males and 14 females) who underwent single or double segment MIS lumbar fusion through a posterior approach were prospectively enrolled in this study. The pathology included degenerative spondylolisthesis in 16 cases, isthmic spondylolisthesis in 5, recurrent disc herniation, degenerative lumbar spinal stenosis, post-infective spondylitis instability and spondylolysis in one each. The degrees of spondylolisthesis were limited to Myerding grade of 1 or 2. No major spinal deformity case was included in this study. The spinal levels included were within L3 to S1. Only the recurrent disc herniation case had a history of previous spine surgery. 11 patients had the operation done using C-arm (GE Health OEC 9900 Elite, Fairfield USA) and 14 patients underwent an operation using O-arm® Surgical Imaging with Stealth Station® Navigation System (Medtrontic, Minneapolis USA) using its standard mode. BMIs of the patients were recorded. Each group was further divided into 3 subgroups: transforminal lumbar inter body fusion (TLIF) through a bilateral Wiltse approach, TLIF through a midline approach and posterior lumbar fusion (PLF) through a midline approach to account for the heterogeneity within each group. All surgeries were performed by the single surgeon (YK).

We use the fluoroscopy mode of O-arm to locate the level to be navigated and then obtained 3D images using its CT mode. One CT scan was enough to include the whole region of interest in all cases. Further X-rays may be taken intra-operatively especially while inserting the cage during TLIF for better positioning of the cage. After completion of the instrumentation, another CT scan was obtained for assessment of implant placement. If any adjustments had to be made, another CT scan would be obtained for final confirmation.

The RE to surgeon was registered by a personal finger dosimeter. The reading of the internal dose registration systems of C-arm and O-arm devices were obtained and then converted into effective dose (ED) received by a patient through the following equations:

For the C-arm and O-arm as a 2D fluoroscopy scanning, ED (mSv)=Skin Surface Doses (SSG) (mGy) × Tissue Weighting Factors' sum.

For the O-arm (CT mode) ED (mSv)=Dose Length Product (DLP) x Conversion Index.

Conversion index for adult trunk is 0.015 as reported in literature [3].

DLP=CT Dose index weighted (CTDIw) × radiation area

Total ED to patient in O-arm group was thus=ED (CT mode) + ED (2D fluoroscopy scanning)

The Tissue Weighting Factors recommended by the International Commission on Radiological Protection 2007 [4] were utilized.

The age, BMI, blood loss, operation time, one week post-operative CRP, ED to patients and radiation dose to surgeon were compared by using unpaired t-test with p value set at <0.05 to consider as statistically significant.

Results

The C-arm and O-arm cohorts were matched for age (64.45 ± 19.47 years *vs.* 65.36 ± 17.71 years in O arm and C arm respectively) and the BMI (25.23 ± 3.37 kg/m2 *vs.* 25.10 ± 3.18 kg/m^2 in O-arm and C-arm respectively). There were two asymptomatic screw misplacements in C-arm group and no screw misplacements or complications in O-arm group.

The mean operation time was identical in both groups (133 min in C-arm and 144 min in O-arm group) while the mean intraoperative bleeding was significantly smaller in O-arm group (123 ml *vs.* 241 ml in C-arm group, p=0.005). The mean CRP values at one week postoperatively were two times higher in the C-arm group (1.4 in O-arm *vs.* 2.8 in C-arm group, p=0.1) (Table 1).

Mean exposition time was significantly longer in the C-arm group (9.5 min *vs.* 0.57 min, p=0.0005).Mean surgeon RE was 2.19 ± 1.36 mSv in C-arm group and undetectable (0 mSv) in O-arm group (p=0.0003) (Table 2). This was because the personnel can wait outside the operation room to avoid RE during the acquisition of CT images. In the subgroup of PLF, RE in C-arm was significantly higher than that in o-arm (1.46 ± 0.64 *vs.* 0). The surgery was performed using navigation without any further RE.

Using O-arm with navigation system led to a reduction of the ED to the patient by half compared to C-arm group (Table 3). The mean patient ED was 41.85 ± 16.86 mSv and 16.09 ± 10.5 mSv in C-arm and O-arm groups respectively (p=0.0004). The mean EDs to a patient were also significantly less in O-arm subgroup of PLF compared to C-arm (37.4 ± 9.73 *vs.* 12.03 ± 8.30). Because of limited number of cases, the t-test could not be performed for the TLIF subgroups but the mean ED sin O-arm groups were much less than in corresponding C-arm groups (41.79 *vs.* 25.60 ± 11.11 mSv and 59.59 ± 37.31 mSv *vs.* 14.59 mSv in the bilateral Wiltse approach TLIF and posterior approach TLIF respectively).

Discussion

The MIS spinal fusion surgery keeps increasing in popularity because of its obvious benefits. This means that more and more patients will undergo this highly imaging dependent surgery. Risk of cumulative RE to both surgeons and patients is a growing concern.

Table 1: Demographical data of the patients.

C-arm

No.	Sex	Age	Pathology	Surgery	Number of Instrumented levels	RE to surgeon (mSv)	ED to patient (mSv)	Exposition (min)	BMI
1	F	62	L5/S1 IS	W- TLIF	1	4.2	41.97	21.3	24.77
2	M	51	L4/5 pseudo arthrosis following spondylodiscitis	M- TLIF	2	4.1	85.97	13.7	26.64
3	M	15	L5/S1 IS	M-TLIF	1	4.1	33.20	10.5	17.46
4	M	77	L4/5 DS	PLF	1	0.7	21.06	8	23.29
5	F	81	L3/4 DS	PLF	2	2.6	43.42	8	23.50
6	M	55	L4/5 Recurrent disc herniation	PLF	1	1.1	30.17	8.9	24.78
7	F	80	L4/5 DS	PLF	1	1	34.17	6.8	27.37
8	M	63	L4/5 DS	PLF	1	1.1	51.98	8.6	26.73
9	M	69	L4/5 DS	PLF	1	2.1	37.75	7.1	23.88
10	M	76	L4/5 DS	PLF	1	1.3	34.53	5.6	25.61
11	F	80	L4/5 DS	PLF	1	1.8	46.13	6.7	30.61

O-arm

No.	Sex	Age	Pathology	Surgery	Number of Instrumented levels	RE to surgeon (mSv)	ED to patient (mSv)	Exposition (min)	BMI
1	M	41	L5/S1 IS	W-TLIF	1	0	34.78	1.4	23.36
2	M	26	L5/S1 IS	W-TLIF	1	0	32.79	1.6	25.67
3	M	39	L5/S1 IS	W-TLIF	1	0	10.32	1.3	26.56
4	F	76	L5/S1 IS	W-TLIF	1	0	24.49	0.9	27.97
5	F	72	DLS	M-TLIF	1	0	14.59	0.8	20.65
6	F	56	L3 DS	PLF	1	0	9.25	0.2	26.95
7	F	78	L4 DS	PLF	1	0	32.96	0.3	25.85
8	F	69	L4 DS	PLF	1	0	9.17	0.3	19.13
9	F	70	L4 DS	PLF	1	0	7.05	0.1	23.66
10	F	76	L4 DS	PLF	1	0	5.65	0.2	20.85
11	F	75	L4 DS	PLF	1	0	8.30	0.1	26.16
12	F	77	L4 DS	PLF	1	0	12.79	0.4	30.59
13	F	84	L4 DS	PLF	2	0	8.70	0.1	27.11
14	M	76	L4 DS	PLF	1	0	14.41	0.4	26.84

Remarks: DS: Degenerative Spondylithesis; IS : Isthmic Spondylosis; DLS: Degenerative Lumbar Spinal Stenosis; W-TLIF: Transforminal Lumbar Interbody Fusion Throughwiltse Approach; M-TLIF: Midline Approach Transforminal Lumbar Inter Body Fusion; PLF: Midline Approach Posterolateral Fusion.

Table 2: Radiation exposure to surgeon (mSv).

	C-arm	O-arm	P value
W-TLIF	4.2	0	n/a
M-TLIF	4.1± 0	0	n/a
PLF	1.46 ± 0.64	0	<0.01
overall	2.19 ± 1.36	0	<0.01

Table 3: Radiation exposure to patient (mSv).

	C-arm	O-arm	P value
W-TLIF	41.79	25.60 ± 11.11	n/a
M-TLIF	59.59 ± 37.31	14.59	n/a
PLF	37.4 ± 9.73	12.03 ± 8.30	<0.01
overall	41.85 ± 16.86	16.09 ± 10.50	<0.01

The complications of RE not only include the acute or deterministic effects but also the late or stochastic consequence. The deterministic effects such as skin erythema, tissue necrosis occur at the radiation levels never encountered in spinal surgery [4-6]. The stochastic effects mainly involve long term effect of carcinogenesis and hereditary disease after low dose radiation exposure which can manifest 10-20 years later. The probability of combined stochastic effect is around 5% Sv^{-1} which should not be neglected in our daily practice (Table 4).

This is especially true in the era of wide utilization of imaging. From 1980 to 2005, there was a 20 times increase in CT scanning in United States [7]. The cumulative radiation exposure to patient from surgery and also pre-operative and post-operative imaging can be up to several times of the background radiation for years [8]. Spine surgeons should be aware that the radiation dose for spine X-ray is commonly higher than for other areas and it is highest for the lateral lumbar spine X-ray [9]. Same is true concerning CT. CT of axial skeleton is associated with substantial increase in RE and it is highest for lumbar spine CT [10]. Therefore, choosing the imaging tool and technique is important in order to satisfy the rule of 'As Low as Reasonably Achievable (ALARA)' radiation exposure.

Table 4: Detriment-adjusted nominal risk coefficients for stochastic effects after exposure to radiation at low dose rate (10^{-2} Sv^{-1}).

Exposed Population	Cancer	Heritable effects	Total Detriment
Whole	5.5	0.2	5.7
Adult	4.1	0.1	4.2

Fluoroscopy (C-arm) is the most traditional way for image guidance. In non-instrumented surgery such as microdiscectomy, Michael et al. [11] found that the surgeon is exposed to more radiation in MIS lumbar microdiscectomy than open herniotomy. This was due to extra fluoroscopy needed for tubular retractor placement and adjustment. Moreover, Rampersaud also found that fluoroscopically guided thoracolumbar pedicle screw insertion can expose the surgeon to 10 to 12 times the RE of other non-spinal musculoskeletal procedures [12]. The radiation exposure was still within acceptable range in some surgeries such as TLIF or lateral lumbar interbody fusion but it can be up to unacceptable levels in others such as adolescent idiopathic scoliosis instrumentation [13-15]. Computer assisted surgery (CAS) is becoming another choice of intraoperative imaging and it provides intra-operative 2D or 3D navigation. Nakagawa et al. [16] used fluoroscopic based 2D image computer assisted surgery (virtual fluoroscopy) for the insertion of pedicle screws on a plastic model. He found the accuracy of the navigation system was satisfactory and he expected reduction in radiation exposure by using this system. Further studies also showed that CAS can reduce the chance of malposition of pedicle screws in scoliosis surgery and cervical pedicle screw surgery [17,18]. Those cases are technically demanding because of small pedicle size and distorted anatomy.

Besides the high accuracy and avoidance of the aforementioned drawbacks of fluoroscopy, RE remains a concern in CAS. Slomczykowski et al. [19] found that using CAS based on pre-operative CT for pedicle screw insertion requires a higher RE than intraoperative fluoroscopy. He suggested that optimizing the CT protocol to reduce the RE and the advantages of CAS justify the radiation when indicated.

Use of navigation-assisted fluoroscopy is able to reduce the radiation dose but it only provides 2D images [20]. The Iso-C, a CT based CAS with intra-operative 3D image acquisition was developed and it was proven to reduce the radiation exposure to both surgeon and patient in balloon kyphoplasty and pedicle screw insertion [21,22]. O-arm with navigation system also serves the same purpose but its radiation dose had to be justified. Research found that radiation received by patients of the standard CT mode of O-arm is less than that of a standard abdominal CT scan [23]. The radiation to surgical team was minimal and far below the occupational exposure limit as they can wait in sub-sterile area during imaging [24]. However Parks et al. [25] found that the surgeon received more radiation while using fluoroscopy mode of O-arm than C-arm. Therefore, evaluation of the total radiation dose and comparison with other radiological tools is needed.

In our study, O-arm with navigation system exposed the surgeon to minimal radiation as they went to the sub-sterile area during image acquisition. Also the exposition time was significantly longer in C-arm group producing much higher RE to the patient. The same results were also demonstrated by other authors. We also found that the ED to patient was no more than a half of C-arm's. This means that O-arm is a safer option for image guidance in view of high accuracy and lowers RE. Besides, as CT mode of O-arm can provide navigation for several levels after one image acquisition session, this advantage will grow in multilevel surgery. Moreover, screw misplacement is picked up on the intraoperative CT and corrected immediately obviating the need for revision surgery.

Tabaree et al. [26] conducted a cadaveric study that showed different findings. It is difficult to compare their results with ours because of different measurement methods for radiation exposure, different study subjects (*in vivo vs.* cadaveric) and also different imaging protocol. The high resolution mode of O-arm will subject the patient to higher radiation dose than standard protocol that we used. Simply difference in the position of the imaging machine can also increase the radiation dose up to 3 times [27]. Besides, the result of the study should be interpreted with caution as it showed the radiation exposure to surgeon's hand and thyroid was undetectable after insertion of 12 thoracic pedicle screws under C-arm guidance. Surgeon's hand is supposed to be the closest to the radiation source but it appeared to receive the least radiation dose. Moreover, in the MIS group, although they were working on the lumbar spine, the radiation exposure to the sternum was even higher than that to anterior abdomen. Similar situation happened in the O-arm group in which the radiation to the anterior abdomen is higher than that of sternum while performing thoracic pedicle screw insertion. Erik Van et al. [28] using a database of more than a thousand pedicle screws places with the help of O-arm navigation found that if the surgeon is confident of the screw position, the risk of malposition of screw on CT is only 1%. In their opinion this means that an intraoperative CT scan after the screw placement to search for misplacements might not be necessary. However, we strongly believe that finding out a misplaced screw and correcting the error without the need for a reoperation in at least 1 out of every 25 surgeries is well worth taking routine post instrumentation intraoperative CTs.

The limitations of this study are limited cohort, indirect measurements of the patients' RE and the fact that the CDTI used for our calculations is based on results obtained from a standard phantom rather than real human body. Further development of technologies for accurate ED measurement might be needed.

Conclusion

Although we introduced O-arm at our facility to allow the use of precise navigation during surgery, we anticipated an increase in RE. However, notwithstanding 2 or more CT acquisitions per surgery the surgeon's RE was completely avoided and patient's RE was reduced to less than a half that of C-arm's, which proves that O-arm is beneficial for both surgeon and patient in MIS lumbar fusion surgery.

Although O-arm assisted surgery requires additional time for reference frame placement, instrument registration and bony landmark verification, the mean operation time was statistically identical in O-arm and C-arm groups in our study which means that actual instrumentation time got shorter in O-arm group.

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