Original Research

Inverted C-arm Orientation During Simulated Hip Arthroscopic Surgery

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Background: Fluoroscopic guidance is routinely utilized during hip arthroscopic surgery. Previous studies have shown that the C-arm orientation can significantly affect radiation exposure for both the surgeon and the patient during orthopaedic procedures. However, this has not been previously assessed for hip arthroscopic surgery.

Hypothesis: Using an inverted C-arm during hip arthroscopic surgery will reduce radiation exposure to the patient and surgeon.

Study Design: Descriptive laboratory study.

Methods: A simulation study measured scatter radiation during hip arthroscopic surgery performed in the supine position under fluoroscopic guidance with an anthropomorphic pelvic phantom on a radiolucent operating table. Radiation exposure tested 2 different C-arm orientations: standard and inverted. Testing was performed at 6 locations corresponding to the patient, surgeon's neck, surgeon's waist, surgical technician, anesthesiologist, and radiology technician. Statistical analysis was performed using univariate and multivariate analyses assessing radiation exposure between the C-arm orientations. A risk calculation for carcinogenesis was performed based on reported radiation dosages.

Results: Radiation exposure (in mGy/min) was more than 100-fold higher for the patient compared with the surgeon in both C-arm orientations. The inverted C-arm orientation resulted in a 2.48-fold decrease in patient radiation exposure when compared with the standard orientation (10.8 mGy/min vs 26.8 mGy/min, respectively). There was a small but significant increase in surgeon radiation exposure in the inverted orientation compared with the standard orientation (0.072 vs 0.067 mGy/min, respectively). The patient's carcinogenesis risk was decreased 2.64-fold with the inverted orientation compared with the standard orientation (1.4×10^{-5} vs 3.7×10^{-5}, respectively).

Conclusion: The inverted C-arm orientation resulted in a 2.48-fold decrease in patient radiation exposure with a 2.64-fold decrease in the carcinogenesis risk compared with the standard orientation. Inadvertently, the inverted orientation provided a 9-cm increase in the surgeon's working area. Our data supported the clinical utilization of the inverted C-arm orientation during hip arthroscopic surgery to minimize patient radiation exposure. Although there was a minimal but significant increase in surgeon radiation exposure with the inverted orientation, we believe that this is negligible when incorporated with standard leaded protective equipment as contrasted with the significant dose reduction for the patient as well as the decreased risk of carcinogenesis and hereditary disorders.

Clinical Relevance: Patients undergoing hip arthroscopic surgery routinely acquire radiation exposure during the use of the C-arm. Measures to minimize radiation via the inverted C-arm orientation will decrease the unnecessary risk to the patient while continuing to allow for optimal treatment.

Keywords: carcinogenesis; radiation risk; cam/pincer; scatter radiation; femoroacetabular impingement

Hip arthroscopic surgery is an increasingly common procedure for the treatment of femoroacetabular impingement (FAI) as well as other intra-articular and extra-articular abnormalities about the hip.[9,18] Hip arthroscopic surgery has seen tremendous growth in its utilization, estimated between 365% and 500% over the past decade.[2] Outcomes for the arthroscopic treatment of FAI have shown significant improvements in subjective and objective measures of hip pain and lesions, with a good to excellent result observed in 75% of hips at a minimum 1-year follow-up.[16] A 10-year follow-up has been associated with continued substantial improvements in preoperative nonarthritic hips treated with arthroscopic surgery for FAI.[6]

Fluoroscopic guidance is routinely required during hip arthroscopic surgery, exposing both the patient and the surgeon to associated radiation risks. In standard C-arm positioning, defined as the emitter being positioned beneath the table, Budd et al[5] found an average radiation dose of 52 mGy

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transmitted to patients during hip arthroscopic surgery. Given the proximity of radiation-sensitive organs during hip arthroscopic surgery, limiting the time and number of fluoroscopic images is of vital importance. Despite the steep learning curve of hip arthroscopic surgery, a single surgeon may reduce his or her fluoroscopy time by 25% over a year of clinical practice, thus reducing the cumulative radiation exposure for the patient and surgeon.[9,16] Additionally, previous studies have shown that the use of an inverted C-arm orientation can significantly reduce radiation to both patient and surgeon during upper extremity surgery.[21] However, no objective data exist regarding C-arm orientation and radiation exposure during hip arthroscopic surgery.

The purpose of this study was to determine if the C-arm orientation would affect radiation exposure to the surgeon and patient during simulated hip arthroscopic surgery. We hypothesized that inverted C-arm positioning would result in decreased surgeon and patient radiation exposure.

METHODS

After obtaining exemption from our institutional review board, an anthropomorphic pelvic model underwent a fluoroscopic examination in the operating room, simulating an arthroscopic hip procedure. Scatter radiation was measured using the RaySafe X2 device, a validated and tested tool that is used for calibrating and measuring radiation by our hospital's Radiation Safety Department. The RaySafe X2 allows for remote measuring of live radiation exposure, with the data directly exported to a Microsoft Excel spreadsheet for analysis. Radiation was measured in units of mGy/min, providing a rate of radiation exposure that can be extrapolated to various usage protocols based on surgeon preference.

An acrylic anthropomorphic pelvic phantom model (Sectional Lower Torso Phantom, SK 250; The Phantom Laboratory) was chosen following a previously validated method.[4,13] The model was placed supine on a radiolucent operating table (radiographic imaging table from Image Diagnostics) with an adjacent mannequin to simulate the location of the orthopaedic surgeon (Figure 1). A radiolucent table, rather than the standard distraction table, was used because of the inability to mount the phantom limb adequately. A GE Healthcare OEC 9900 Elite Mobile C-arm was used for the fluoroscopic examination during the study. Standard positioning was defined as having the emitter placed below the level of the table, and inverted positioning was defined as the emitter positioned above the table/patient, as seen in a clinical example in Figure 2. Radiographic settings consisted of 73 kVp and 2.45 mA. Positioning of the C-arm, patient, and surgeon was the same for all radiographic conditions. The emitter was positioned 49 cm from the patient in the standard orientation and 58 cm from the patient in the inverted orientation, which equated to the maximal distance of the superiorly positioned aspect of the C-arm, either the emitter or base, from the anterior aspect of the hip. These measurements were recorded to represent the surgeon's working area for the standard and inverted orientations.

Devices for detecting radiation were placed at 5 locations, representing the most common people exposed to radiation within the surgical suite: surgeon, patient, surgical technician, anesthesiologist, and radiology technician. All detectors were placed outside of any leaded protective equipment. The patient's detector was placed directly over the hip joint, in line with the emitter of the C-arm. Table 1 shows the distances from the emitter for each of the positions. The mock surgeon had radiation detection devices placed to correspond to the thyroid location and body location (Figure 3). Data were collected after 1 minute of C-arm utilization in both the inverted and standard orientations, with 3 trials conducted for each orientation. A calculation for the carcinogenesis risk from ionizing radiation exposure was performed for the 2 C-arm orientations using the equation previously reported by Budd et al.[5]

Statistical analysis was performed using IBM SPSS Statistics version 24. Significance was predetermined as $P < .05$. Univariate analysis was performed using Student t tests to assess for differences in scatter radiation between the 2 C-arm orientations for each tested location. The distances of the tested locations from the C-arm were used to assess the effect of distance on radiation exposure. Previous studies have shown that patient outcomes are superior for surgeons with a minimum of 550 arthroscopic hip cases[7]; as such, this value was used for the estimated career caseload. The time of fluoroscopy use reported in the literature is highly variable, ranging from 12 seconds to 24 seconds per recent studies.[12] As such, to assess the cumulative effect of radiation differences in the C-arm orientation, doses were extrapolated using an estimate of 15 seconds of fluoroscopic time during each case across a career caseload of 550 cases.

RESULTS

Significant differences were apparent between the 2 C-arm orientations with regard to the surgeon's working area, with an additional 9 cm of working space in the inverted orientation compared with the standard orientation (58 cm vs 49 cm, respectively). The mean scatter radiation doses for the different testing locations, according to the C-arm orientation, are summarized in Table 2. Radiation exposure

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Ethical approval for this study was obtained from the Department of the Army.

Figure 1. Clinical image demonstrating simulated hip arthroscopic surgery performed under fluoroscopic guidance in the standard C-arm orientation with the anthropomorphic pelvic model positioned in the supine position and the mock surgeon depicted in standard personal protective equipment.

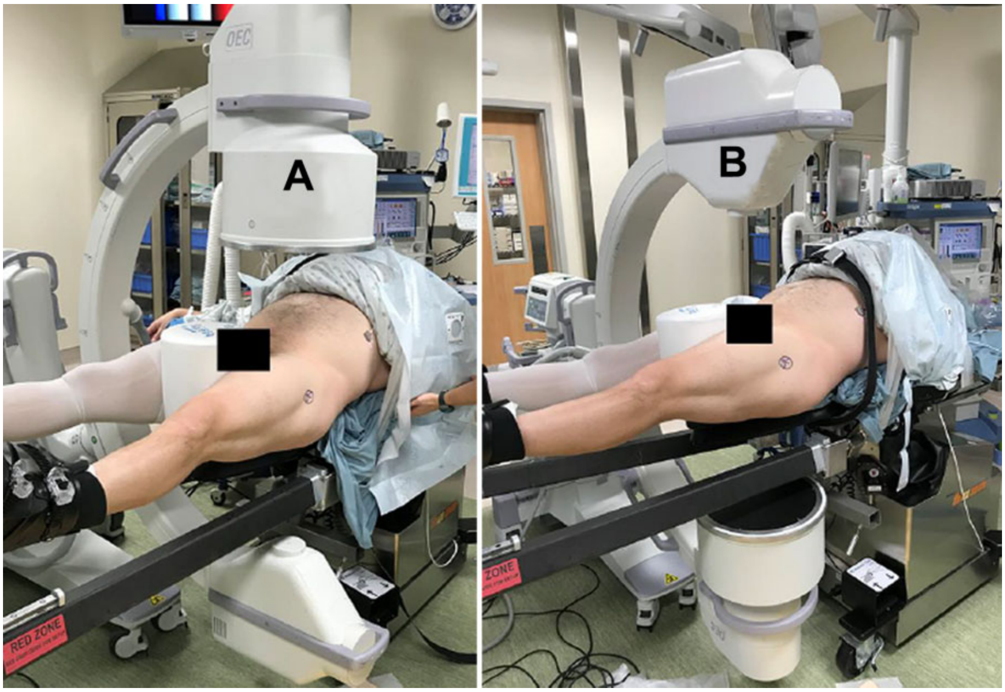

Figure 2. Clinical images demonstrating fluoroscopic C-arm orientations used for testing: (A) standard orientation and (B) inverted orientation.

TABLE 1
Linear Distances of Radiation Exposure Testing Locations From the Emitter

Location	Standard, cm	Inverted, cm
Patient	49	58
Surgeon's neck	122.77	56.60
Surgeon's waist	69.31	73.76
Surgical technician	192.96	155.27
Anesthesiologist	199.81	180.28
Radiology technician	237.59	209.69

Figure 3. Clinical image depicting the mock surgeon positioned adjacent to the anthropomorphic pelvic model with scatter radiation measurement devices arranged for recording radiation exposure at the (A) body and (B) thyroid.

(in mGy/min) was more than 100-fold higher for the patient in comparison with the surgeon in both C-arm orientations.

The inverted C-arm orientation resulted in a 2.48-fold reduction in radiation exposure for the patient in comparison with the standard orientation (10.8 mGy/min vs 26.8 mGy/min, respectively; $P < .001$; 95% CI, 26.7-26.8 mGy/min). Surgeon radiation exposure demonstrated a minimal but significant difference, with a higher dose in the inverted orientation compared with the standard orientation (0.072 mGy/min vs 0.067 mGy/min, respectively; $P < .01$; 95% CI, 0.063-0.068 mGy/min). Radiation dosage for the remaining testing locations with the exception of radiology technician demonstrated, similar to surgeon exposure,

TABLE 2
Mean Radiation Exposure Measurements at Selected Testing Locations Corresponding to the Clinical Staff

Location	Standard, mGy/min	Inverted, mGy/min	*P* Value
Patient	26.8	10.8	<.001
Surgeon's neck	0.0124	0.0295	<.001
Surgeon's waist	0.0665	0.0720	<.01
Anesthesiologist	0.00093	0.00129	<.001
Surgical technician	0.000193	0.000269	<.001
Radiology technician	0.000132	0.000127	>.05

minimal but significant higher radiation exposure in the inverted orientation, as seen in Table 2.

Although our data collection was in 1-minute intervals, the RaySafe X2 provides real-time radiation exposure rates; thus, <1-minute and >1-minute radiation data can be extrapolated. Assuming an average fluoroscopy time of 15 seconds per case with a cumulative career caseload of 550 arthroscopic cases using standard protective equipment, surgeon radiation exposure using the inverted C-arm orientation was estimated to be 1.2 mGy, 40% of the patient's exposure during a single case ($P < .05$).[1,7] The calculation of the patient's carcinogenesis risk due to ionizing radiation determined a risk of 1.4×10^{-5} for the inverted orientation compared with 3.7×10^{-5} for the standard orientation. Using the patient's carcinogenesis risk calculation, there was an estimated 62% risk reduction in radiation exposure with the inverted orientation.

DISCUSSION

Fluoroscopic guidance is a necessary aid when performing hip arthroscopic surgery for the treatment of FAI to facilitate surgery as well as ensure adequate bony resection. However, this setup does place the patient's gonads at direct risk to radiation exposure, with the potential increased risk of carcinogenesis. We demonstrated that through the use of an inverted C-arm orientation, the patient's radiation dosage during simulated hip arthroscopic surgery can be reduced by half when compared with a standard C-arm orientation. Although the surgeon receives a significantly higher dose of radiation in this orientation, it is a clinically insignificant increased dose (0.0055 mGy/min) that is 100-fold less than the patient's exposure during 1 case. Additionally, the surgeon's working area is improved with the inverted orientation in our study, with a 9-cm additional clearance when compared with the standard orientation.

The nature of the orthopaedic surgeon's practice places him or her at a unique balance point of necessary versus unnecessary radiation exposure. Although hospital policies place guidelines for acceptable occupational radiation exposure, the International Commission on Radiological Protection (ICRP) recommends a maximum of 20 mGy/y of occupational exposure.[10] The ICRP cautions that radiation exposure past the recommended limitations may cause local skin damage and systemic absorption, leading to DNA changes, with the risk of developing a possible malignancy.[25] Even more important is the orthopaedic surgeon's role in managing patient radiation exposure, especially during fluoroscopically guided procedures in which patient exposure can average as high as 40 mGy/min compared with 0.2 mGy/min for the surgeon.[19]

Radiation exposure poses a 2-tiered effect on the human body. In the acute setting, it can cause damage to skin and hair (a deterministic effect, measured in Gy), and with chronic use, it can cause carcinogenesis (a stochastic effect, measured in rem). High doses of radiation (2 Gy) are required to produce skin burns and hair loss, which are levels much higher than what is seen for orthopaedic patients or surgeons. However, a lifetime exposure of 100 rem can increase the risk of death from cancer by 5%.[3,7] On average, a person will be exposed to approximately 300 mrem as part of natural background radiation.[22] The use of personal radiation protective equipment, such as lead aprons and thyroid shields, with a thickness of 0.25 to 0.5 mm, can prevent the majority of radiation transmission to protected areas during procedures; however, it should be noted that the arms, hands, and other unprotected areas are still exposed. Although a useful method of preventing deterministic and stochastic effects, the patient's positioning and operative site can preclude the ability of providing appropriate protection.[1,8]

The reported data are consistent with findings in the previous literature of a significantly higher radiation exposure to patients compared with surgeons. This is of particular concern given the close proximity of the patient's gonads, one of the more radiation-sensitive organs in the body, to the surgical field and the inability to appropriately shield these organs. Canham et al[7] investigated the link between radiation exposure and increased cancer risk in patients undergoing hip arthroscopic surgery, finding an average of 4.9 mGy of radiation exposure with a lifetime increased risk of cancer of 0.025%. In contrast, the surgical staff had increased radiation exposure from 7 to 9 mrem and an increased lifetime risk of death from cancer by 0.0005%.[7]

Budd et al[5] examined the patient's effective radiation dose and the carcinogenic potential during hip arthroscopic surgery performed in the lateral position. Using an excess mortality coefficient of 5.5×10^{-5} mGy^{-1} applied to the patient's effective radiation dose to assess the risk of fatal cancers and hereditary disorders, they found an increased risk for fatal cancers of 0.006 per 10^6 female patients and 0.06 and 0.1 per 10^6 male patients for hereditary disorders.[5] Applying their excess mortality coefficient of 5.5×10^{-5} mGy^{-1} for the gonads to the investigated C-arm orientations, this would correspond to a risk factor of 2.68×10^{-4} for the standard orientation and 1.08×10^{-4} for the inverted orientation.

Agarwal[1] discussed potential methods for significantly reducing exposure to include lead aprons, thyroid shields, decreased exposure times, C-arm orientation, and C-arm magnification. Lead aprons have shown to reduce exposure considerably depending on the fluoroscopic projections, with reductions of up to 16-fold.[1,20] Unfortunately, with the setup of hip arthroscopic surgery, there is no available method to appropriately shield the patient's gonads. As such, one could infer that with the patients receiving higher levels of radiation, their lifetime cancer risk would be increased as compared with the surgeon's overall risk during hip arthroscopic surgery. Using the excess mortality coefficient as described by Budd et al,[5] the surgeon's increased risk of carcinogenesis would be 3.96×10^{-6} compared with the patient's 1.4×10^{-5} in the inverted orientation.

All practitioners utilizing ionizing radiation should observe appropriate radiation safety principles/guidelines during clinical application.[11] These guidelines rely on the principle of increasing the distance between the point of interest (patient, surgeon, surgical technician, etc) and the radiation source and limiting the time of radiation exposure. One technique for maximizing the distance of the patient from the radiation emitter involves the use of the inverted C-arm orientation. Numerous previous studies have investigated the effect of C-arm orientation for various orthopaedic procedures.[10,12,14,15,23,24] Giordano et al[11] found that by maximizing the distance of the emitter to the patient, a 2-fold reduction could be obtained for patient exposure. Tremains et al[21] found decreased patient and surgeon radiation exposure with the use of the inverted C-arm orientation during simulated upper extremity surgery. Jones et al[15] used a similar methodology to the current study to investigate the C-arm during lumbar spine surgery. Consistent with our data, there was a decrease in patient radiation exposure with the inverted orientation and an increase in surgeon exposure, with the similar finding of an increase in the surgeon's working area. We believe that our data support the clinical utilization of an inverted C-arm orientation during hip arthroscopic surgery to minimize patient radiation exposure.

Limitations

Our study has several limitations. Our data reflect the use of a validated synthetic anthropomorphic model to simulate a clinical atmosphere. Although we can extrapolate from our data the significance of direct radiation exposure, the true scatter radiation dose and radiation exposure may vary in an actual clinical setting. This study was designed specifically to evaluate the hip, and the results may not extrapolate to other body parts or procedures given the anatomic differences as well as radiographic settings, tube voltage, and current needed to image that specific body part. In addition, the use of an anthropomorphic model does not allow for the assessment of other confounding variables that would be associated with risks of radiation exposure, such as the patient's stature and body mass index (BMI). An increased BMI is associated with an increased effective radiation dose. Specifically, obese patients with a BMI of 30 to 39.9 kg/m^2 have a more than 2-fold increase in the mean adjusted effective radiation dose, and morbidly obese patients with a BMI of $\geq$40 kg/m^2 have a greater than 3-fold increase versus that in normal weight patients with a BMI of $<$25 kg/m^2.[17]

In addition, the radiolucent table used for this study was selected for the ease of study design and the ability to accommodate the image intensifier in the inverted orientation. Many surgeons perform hip arthroscopic surgery on Mizuho OSI Hana or fracture tables. These tables have different radiographic properties, which could change the scatter to the patient and surgeon. It is possible that other facilities may not be able to accommodate the inverted orientation because of the equipment or table used, which thus limits their capabilities to implement the inverted orientation solely for technical reasons.

Our study did not assess the quality of imaging when comparing the inverted and standard orientations. Anecdotal data from our facility's orthopaedic surgeons performing hip arthroscopic surgery have seen no difference in image quality with the inverted orientation. Further investigation is necessary to assess for variations in image quality in the 2 orientations.

Finally, our data were collected without considering the use of personal protective equipment. The standard of practice in our hospital is for all staff in the operating room to wear lead aprons and thyroid shields to reduce the risk of radiation exposure when performing fluoroscopically assisted procedures. As such, our data for staff radiation exposure are undoubtedly overestimated.

CONCLUSION

We found a 2.48-fold reduction in patient radiation exposure and a 9-cm increase in the surgeon's working area during simulated hip arthroscopic surgery with the inverted C-arm orientation. Although there was a minimal but significant increase in surgeon radiation exposure with the inverted orientation, we believe that this is negligible when incorporated with standard leaded protective equipment, as contrasted with the significant dose reduction as well as the decreased risk of carcinogenesis and hereditary disorders for the patient.

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