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Review article

Radiation exposure and its safety measures in open and minimally invasive transforaminal lumbar inter-body fusion: A literature review

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Abstract
Radiation is a phenomenon in which the wave emitting from a particular source travels outwards in all directions. There are numerous types of radiations. But one which is mostly harmful to a person in health sector is ionizing radiations generated from X-ray tubes. Spine surgeons are most at risk of this ionizing radiation exposure than others, as there is frequent requirement of fluoroscopy during spine surgeries. Two such procedures are open Transforaminal Lumbar Inter-body Fusion (TLIF) and Minimally Invasive Transforaminal Lumbar Inter-body Fusion (MI-TLIF). Therefore, this paper reviews studies that explored the impact of radiation exposure during open TLIF and MI-TLIF, its related complication and evaluation of occupational hazards to the health workers. Open TLIF and MI-TLIF are the most common procedure of spine surgery which requires intra operative fluoroscopic guidance for the appropriate localization and placement of instrumentation. The length of these procedures increases continuous exposure to the X-rays causing potential short term risks like skin injury and burn, and long term consequences like radiation induced cancers in both patients and surgeons. Although, the clinical benefit of one time procedure outweighs the small radiation risk for the patient, the number of times of exposure increases with each case for the health care provider. However, MI-TLIF has more advantages and is considered to be more beneficial to the patient than Open TLIF making it more popular and widely used. Also, the concern of interest are the findings of different studies, on how to reduce the risk of radiation exposure in surgeons without affecting the efficacy of the procedure.
Keywords: Ionizing Radiations, Fluoroscopy, Open TLIF, MI-TLIF.

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Introduction:

Ionizing Radiation is a type of radiation which has enough energy to break a chemical bond. The energy produced is able to ionize an atom or a molecule, hence removing an electron from them. X-rays from X-ray tubes, gamma rays from radioactive isotopes and higher spectrum of ultraviolet rays from the sun are some example which falls within the range of ionizing radiation [1]. Only the specific amount of the absorbed ionizing radiation can cause adverse health problem. To measure the exposure, total radiation deposited per unit mass on the part of the body should be known. The international (SI) unit of measure for absorbed dose is the gray (Gy), which is defined as 1 joule of energy deposited in 1 kilogram of mass. The old unit of measure for this is the rad, which stands for "radiation absorbed dose." - 1 Gy = 100 rad. Occupational exposure is measured in sieverts, where 100 rems = 1 sievert (Sv) = 1000 millisieverts (mSv) = 1000000 microsieverts (uSv). In general, ionizing radiation is harmful and potentially lethal to living beings but it also has its usefulness in health sectors. Radiation therapy for treatment of cancer and other radiological procedure including Fluoroscopy for the purpose of diagnosis and treatment are examples of it [2-4].

Fluoroscopy is a radiographic imaging technique that shows continuous moving X-ray images in the monitor, allowing the visualization of both bone and soft tissues. With the advances in the medical field, fluoroscopy has become an important asset in the diagnosis and treatment of patients, as it is used in wide variety of examination and treatment procedure. Barium X-rays and enemas, angiograms, placement of stents within the body, orthopedic surgery, spine surgery are some of the procedures which uses fluoroscopy [5,6]. Fluoroscopy uses X-rays; therefore it carries the risks of exposure to ionizing radiation. Although the probability of the radiation related risks are statistically very small, we cannot ignore it completely. The radiation dose exposure to the patients and the health worker is directly proportional to the length of procedure. Longer the length of the procedure, higher the time of exposure and absorption of radiation. There are different types of fluoroscopy machine; the one which is commonly used in TLIF is C-arm fluoroscopy [7].

Transforaminal Lumbar Interbody Fusion (TLIF) is a surgical technique made famous by the harms et al [8], in which spinal vertebra and disc is stabilized by fixing a solid bone or graft between them, hence completely eliminating their movement. The goal of the surgery is to reduce nerve irritation and pain. It is performed in patients with the spine problems like nerve compression with associated pain, spondylolisthesis, degenerative disc disease and other back problems. As it joins or fuses two or more vertebra together by removing the intervertebral disc in between them, it is called a fusion surgery. In this procedure, the spine is approached from the back of the body which makes it easier to assess by decreasing the amount of surgical muscle dissection, nerve and the theca sac reaction and manipulation [9-11]. With the use of TLIF, the need of anterior spine surgery has decreased and in doing so it has also help avoid the associated complication from anterior spine surgery. Thus, it has shown to be safe and effective procedure [10, 12-15].

There are 2 types of TLIF: Open TLIF and recently developed Minimally Invasive TLIF (MI-TILF). During open TLIF, large incision is made to open up the spine and remove the lamina to expose the discs underneath. Through the incision, cutting and retracting of the spinal muscle is done to reach the vertebral space. Due to this reason, it takes longer time for a patient to recover after the surgery [16-19]. Now a day, MI-TLIF has been a popular alternative for open TLIF. Due to the advancement in the intra operative image guided technology, less invasive spinal disorder surgeries has been possible leading to more precise and accurate surgeries [20]. In MI-TLIF, instead of a big incision, small tube is inserted through the skin until it rests on the spine and the entire operation is performed through this tube with the help of fluoroscopic imaging technique making it much safer than open TLIF. The amount of muscle tissue cut or retracted and blood loss is greatly reduced making shorter post-operative recovery period [16, 21, 22]. Although MI-TLIF decreases postoperative pain and disability, the limited views of the surgical field require extensive use of intra operative fluoroscopy. This causes higher level of ionizing radiation exposure to the patient and the surgical team. Major complications shared by both MI-TLIF and Open TLIF are allograft malposition, pedicle screw malposition, and infection while some minor complications are hematoma, anemia, and cerebrospinal fluid leakage [16].

Key messages:

1. Radiation exposure to the surgeon during MI-TLIF is almost 3 times higher than in Open TLIF.
2. Adverse effects of long standing ionizing radiation on human bodies include cutaneous skin injuries, different types of cancers, cataracts and genetic mutations.
3. Navigation-assisted fluoroscopy decreases radiation exposure during minimally invasive spine surgery and Pulsed fluoroscopy reduces fluoroscopy time by 76% and radiation dose by 64% compared with continuous fluoroscopy.
4. The maximum annual dose of radiation to the whole body is 5 rem per year, the average c-arm emits an average of 2 rem of radiation per minute but with the protective measures, the surgeon's radiation exposure can be lowered to 0.1 rem per year.

Open TLIF Vs MI-TLIF and ionizing radiation exposure:

Foley et al [21] introduced MI-TLIF for the first time in 2002. Since then, it has been popularly used and widely accepted in the field of spine surgery. This surgical technique minimized the post-operative pain and disability associated with Open TLIF. Both of these techniques have their own advantages and disadvantages [16-18, 22, 23] and both are done using image guiding technique. MI-TLIF has many advantages over Open TLIF. However, it has one major drawback; that is longer period of operation time leading to more exposure to the ionizing radiation [18, 23, 24].

Advantage of MI-TLIF are lower blood loss, less need for postoperative analgesia (only 10% is consumed), early ambulation, less postoperative hospitalization, smaller scar, same clinical and radiological outcome with lesser degree of invasion. On other hand, disadvantage of MI-TLIF are technically more challenging, smaller operative view, longer time, requires more instruments, cost more money and more radiation exposure.

Ionizing radiation exposure in open and MI-TLIF surgery:

Although MI-TLIF decreases postoperative pain and disability, the limited view of the surgical field requires extensive use of intra operative fluoroscopy. This causes higher level of ionizing radiation exposure to the patient and the surgical team.

One meta-analysis study conducted by Nai-Feng Tian et al [25] showed that the open technique needed only half of the X-ray exposure required for the MI procedure. Fluoroscopic need was increased in MI-TLIF during the placement of both the tubular retractor system and pedicle screws. In a recent study [26], during MI-TLIF, radiation dose at the genitals was found to be higher than at any other point in the body except for the surgeon's hands. The surgeon's radiation dose at the chest was also found to be higher in over-weight patients compared to normal-weight. Higher scattered beam is given off from a fat patient than a thin one because the thickness of the body is directly proportional to the amount of X-rays absorbed by the body or scattered throughout the room.

Furthermore, Spine surgeon performing minimally invasive surgical procedures will be at 50 times greater risk of fatal cancer compared to a hip surgeon [27]. During the operation, the radiation decreases with the increasing distance from the patients. Surgeon's hip is the one which is most exposed to the scattered radiation, as the highest level of radiation is beneath the operating table. This is because patient acts as the effective beam stopper. Higher levels of scatter radiation from the C-arm were seen with a 7.7-fold increase in radiation exposure on the tube vs. detector sides [28]. Operator's eyes are more venerable to the radiation exposure when the images are taken with the detector placed away from the operator than towards the operator.

A study conducted by Bindal et al [29] during 1 or 2 level MI-TLIF reported a mean fluoroscopy time of 1.69 minutes per case, and a mean exposure of 76 mrem (0.76 mSv) to the surgeon's dominant hand, 27 mrem (0.27 mSv) at the waist under a lead apron, and 32 mrem (0.32 mSv) at the level of the unprotected thyroid. Lee KH et al. in their study showed that the radiation exposure time for single level MI-TLIF (49.0 seconds) was nearly three times of the single level open TLIF (17.6 seconds) [18]. Similarly, another study also reported that the intraoperative radiation time for MI-TLIF (105.5 seconds) was nearly three times of open TLIF (35.2 seconds) [22]. A systemic review reported that fluoroscopy time in MI TLIF was higher than that of open TLIF, with MI-TLIF patients being exposed to 49 to 297 seconds of fluoroscopy compared to 24 to 123 seconds in the open cohorts [30].

Table 1: Mean Fluoroscopy time by Procedure

Sr #	Author, year	MI-TLIF	OPEN TLIF
1	Bindal et al [29]	101.4s	N/A
2	Lee et al [18]	49s	17.6s
3	Peng et al [22]	105.5s	35.2s
4	Goldstein et al [30]	49-297s	24-123s
5	Ntoukas and Muller [31]	297s	123s
6	Wang et al [19]	84 s	37s
7	Wang et al [32]	92.7s	43.9s
8	Wang et al [33]	46s	24s

Likewise, a study reported that a fluoroscopy time for MI TLIF was 297 sec and OPEN TLIF was 123 sec [31]. A series of study conducted by Wang et al. reported a fluoroscopy exposure time in MI-TLIF to be more than twice than that of Open TLIF.(MI-TLIF 92.7/OPEN TLIF 43.9} [32], {MI-TLIF 46/OPEN TLIF 24} [33], {MI-TLIF 84/OPEN TLIF 37}) [19] and in their 52 revision TLIF case series [34], they found the mean fluoroscopic exposure time in revision MI-TLIF (73 seconds) was significantly longer than that in revision open-TLIF (39 seconds). While Funao H et al. [26] showed that there were no significant differences in radiation doses at all measurement parts between primary and revision MI-TLIF (**Table 1**).

Pulsed Fluoroscopy, Navigation assisted Fluoroscopy and Radiation

Due to the increase risk of radiation exposure, recently, pulsed fluoroscopy and navigation assisted fluoroscopy is widely gaining its popularity. Pulsed Fluoroscopy emits an x-rays beam as a series of short pulses rather than a continuous flow of x-rays, thereby, reducing the amount of time x-rays are emitted. It has become an important tool during radiological procedure which involves long fluoroscopy time like MI-TLIF. It reduces the dose of radiation during live fluoroscopy without loss of image quality or details [35-37]. When compared to the continuous fluoroscopy, pulsed fluoroscopy may reduce fluoroscopy time by 76% and radiation dose by 64% [38]. Goodman et al [39] reported pulsed and low-dose fluoroscopy modes reduced exposure times by 56.7% in spinal interventional procedures (e.g. facet injection, lumbar sympathetic block, radio-frequency ablation). Suitable combinations of pulse frequency and pulse dose can reduce radiation exposure with improved image quality. Altering the fluoroscopic technique to low dose pulsed fluoroscopy and digital spot images can dramatically decrease fluoroscopy time and radiation doses in MI-TLIFs without compromising image quality, accuracy of pedicle screw placement, or efficiency of the procedure [40, 41].

Navigation assisted fluoroscopy can be used to reduce the radiation exposure to the surgical team because during this procedure, the team can step away from the surgical field eliminating the direct radiation exposure. It is said that maintaining a 5–10 cm distance from the patient can reduce the exposure by 25–45% [42, 43].

Radiation hazards

The most common forms of ionizing radiation are alpha and beta particles, or gamma and X-rays. Ionizing radiation can damage any living tissue in the human body in a way which cannot be repaired or it is too severe or widespread to be repaired. The body does attempts to repair the damage and the mistakes made in the natural repair process can lead to cancerous cells.

The adverse effects of ionizing radiations on human bodies are largely divided into two types. The early effects are acute radiation lethality, local tissue damage on the skin or gonads, hematologic effects and cytogenetic effects. The late effects are radiation-induced malignancies such as leukemia and other forms of cancer, local tissue effects, chromosomal toxicity, and/or cataract formation [44-47].

In the orthopaedic field, surgeons must maintain the location of instruments under the X-ray beam, and face a risk of high radiation exposure. The exposure to radiation may cause 2 types of health effects [48].

Stochastic health effect

The chronic exposure to low level radiation causes stochastic health effect. “Stochastic” refers to the likelihood that something will happen. Cancer and DNA mutations are the stochastic health effect. Cancer is known as an uncontrolled of the cells. Radiation causes damage in the cellular and molecular level. During the natural process of repair and replacement of these damage cells in the body, the control processes can be disrupted leading to uncontrolled proliferation of the cells, hence causing cancer. Likewise, another stochastic effect is DNA mutation. The changes occurring in these DNA is known as mutation. DNA which is also known as the blueprint of the cells; replaces and restores by producing the perfect copy of the original cell. When the radiation damages the DNA, during the natural process of repair, the body may fail to restore these blueprints or could create mutation during the repair resulting into teratogenic or genetic mutations which could also be passed to the next generations.

Non stochastic health effect

Acute radiation sickness can occur when most or all of the human body is exposed to a single dose of more than 1 Gy of radiation. A high level acute exposure to the radiation is the cause of non-stochastic health effect. Greater the exposure, more severe is the damage. All the non-carcinogenic health condition due to radiation falls under this category. This is also referred to as radiation sickness or radiation poisoning. It can cause premature ageing and if the exposure dose is fatal, can cause death within 2 month. Some symptoms of radiation sickness are: Nausea, weakness, hair loss, skin burns, diminished organ function.

Health consequences of radiation exposure

Short term consequences [49] are ARS, within minutes or days of exposure: Nausea, vomiting, headache, diarrhoea. After the initial syndrome, patients may feel healthy for short period of time then can be sick with variable syndromes, depending upon the expose dose: loss of appetite, fatigue, fever, nausea, vomiting, diarrheas, and possibly even seizures and coma.

CRI are within a few hours or several days: swelling, itching, tingling and redness of the skin, more severe includes blisters or ulcers, temporary hair loss, long term consequences [49]. Cancer such as cataract: Although single doses of 200 rad induce cataracts, people can tolerate doses up to 750 rads or more without developing cataracts when they accumulate the radiation over time.

Teratogenic mutations resulting from the exposure to the fetuses, smaller head or brain size, poorly formed eyes, abnormally slow growth, mental retardation in children, and trans-generation adverse health effects due to genetic mutation, passed from parents to offspring.

Radiation safety approaches during fluoroscopy use

The current annual whole body limit of radiation is 5 rem per year (**Figure 1**). The average c-arm emits an average of 2 rem of radiation per minute, fortunately with the safety measures the radiation exposure to the surgeon is less than 0.1 rem per year. Still experts agrees there is no ‘safe’ dose of radiations, therefore proper safety measure should be maintained during the procedures.

1. Proper guards: lead gowns, thyroid shields, lead glasses and radio-protective gloves should be used while using the fluoroscopy during surgery. The aprons which are folded and have cracks will not provide effective shielding from the radiations. Leads devices should be regularly checked for its effectiveness and should be changed if it has outlived its suggested life expectancy.
2. If radio-protective equipments are unavailable, simply rotating one's head away from a patient can reduce scattered radiation delivery to the eyes.
3. Standing on the correct side of the table: The greatest radiation exposure occurs on the side of the radiation source due to the combination of primary radiation and scatter radiation, so if possible the surgeon should stand on the opposite side to avoid more.
4. Maximize the distance from source: Whenever possible moving away from the source decreases radiation exposure, because radiation quickly loses intensity as it travels through the air. Standing just one step further away from the source or 1 foot down the length of the table where the beam enters the patient’s body during fluoroscopy can cut surgeon exposure by a factor of four.

5. Hands-Off Technique: Surgeon's hands have the greatest radiation exposure during the TLIF surgery. Proper attention should be taken to the location of their hands while fluoroscopic imaging. A long Kocher clamp can be used to hold jamshidi needle during imaging, in order to keep the surgeons hands away from the direct beam.
6. Limit beam size: The size of the beam is proportional to the amount of radiation emitted. Whenever possible the beam size should be limited by contracting the lead shutters, or collimators as it reduces scatter radiation.
7. Wearing radiation badge: To formally measure the radiation exposure, every staffs should wear radiation badges which measures monthly or yearly radiation dose. This helps staffs to stay in the lesser side of the limited dose.
8. Use of image guidance systems instead of fluoroscopy: Image guidance system based on 3D Intra-operative fluoroscopy helps maintain safety and efficacy during spine surgery, avoiding the deleterious effects of radiation exposure.

ALARA Maximum Annual Occupational Dose Limits	
Whole Body	5000 millirem
Extremities	50000 millirem
Lens of the Eye	15000 millirem
Fetus	500 millirem*

*500 millirem for the fetus is during the gestation period

Figure 1: Alara Maximum Annual Occupational Dose Limits

Management of radiation hazards
1. Treatment focuses on reducing and treating infections, maintaining hydration, and treating injuries and burns. Some patients may benefit from treatments that help the bone marrow recover its function.
2. Lower the radiation dose; the more likely it is that the person will recover. For survivors of ARS, the recovery process may last from several weeks up to 2 years.
3. The cause of death in most cases is the destruction of the person's bone marrow, which results in infections and internal bleeding.
4. If medical attention is not available quickly, gently rinse the area with water. Keep the area clean, dry, and covered until a doctor can provide additional treatment.
5. Medical drugs used in the treatment for radiation exposure and contamination [50].

KI (potassium iodide)
This helps in protecting the thyroid gland. It is a non-radioactive iodine salts which blocks radioactive from being absorbed by the thyroid gland.

Prussian blue
This pill can help remove radioactive cesium and thallium from patient's bodies.

Diethylenetriamine pentaacetate (DTPA)
This can bind to radioactive plutonium, americium, and curium and decreases the amount of time it takes to get out of the body.

Filgrastim
This drug has been used successfully in cancer patients to stimulate the growth of the white blood cells, making patients less vulnerable to infections. It is expected to help patients who have bone marrow damage from very high doses of radiation in much the same way.

Abbreviations
TLIF: Transforaminal Lumbar Inter-body Fusion
MI-TLIF: Minimally Invasive Transforaminal Lumbar Inter-body Fusion
rem: roentgen equivalent in man
rad: radiation absorbed dose
ARS: Acute Radiation Syndrome
CRI: Cutaneous Skin Injuries

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