World Gastroenterology Organisation Global Guideline

Radiation protection in the endoscopy suite

Minimizing radiation exposure for patients and staff in endoscopy: a joint ASGE/IAEA/WGO guideline

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1 Introduction

Ionizing radiation is used in medicine for both diagnosis and therapy. Most gastroenterologists are familiar with the use of radiographic methods for diagnosing gastrointestinal tract abnormalities, evaluating solid organs in the abdomen, and for assistance in placing therapeutic devices. It is essential to establish the appropriate indication for the use of radiation in all circumstances, in order to avoid unnecessary exposure of patients and staff to potentially harmful radiation. Therapeutic uses for radiation are beyond the scope of this guideline.

2 Radiation in gastroenterology

The use of ionizing radiation in gastroenterology is currently going through a transitional period. In the past, gastroenterologists carried out a variety of interventions involving radiation exposure, including gastrointestinal radiography, placement of small-bowel biopsy tubes, esophageal dilation, and assistance with colonoscopy, as well as diagnostic and therapeutic procedures on the pancreaticobiliary system during endoscopic retrograde cholangiopancreatography (ERCP). Most exposure to x-rays in gastroenterology is currently due to ERCP, luminal stent placement, and dilation. Gastroenterologists who are involved in ERCP procedures may work at specialized centers and may perform multiple procedures daily. In all circumstances in which fluoroscopic and/or x-ray equipment is used, gastroenterologists should minimize the risks to patients, themselves, and other members of the staff.

When fluoroscopy is used to assist with colonoscopy, dilation, or luminal stent placement, the shortest fluoroscopy time possible is recommended.

During ERCP, the positioning of catheters and guide wires is verified fluoroscopically. Once contrast injections have been given, fluoroscopy is used to evaluate the anatomy of the ductal systems of both the biliary tree and pancreas and to help assess whether disease is present. Photographic documentation is usually obtained to record the findings by capturing the last fluoroscopic image, spot image, or image sequence, depending on the available features of the equipment used. Finally, fluoroscopy is also needed to assist with therapy—for example, with sphincterotomy, stone extraction, biopsy or cytology, and stent placement. Additional devices that allow direct visualization of the ductal anatomy may ultimately reduce the need for fluoroscopy.

For the patient, the source of exposure is the direct x-ray beam from the x-ray tube. It is estimated that patients receive about 2–16 min of fluoroscopy during ERCP, with therapeutic procedures taking significantly longer. Studies have found that dose–area product (DAP) values of approximately 13–66 Gy/cm^2 are used during ERCP. Effective doses ranging from 2 to 6 mSv per procedure have been reported.

For endoscopists and staff, the major source of x-ray exposure is scattered radiation from the patient, not the primary x-ray beam. Average effective doses of about 0.07 mSv per procedure have been observed for endoscopists wearing a lead apron.

Although the endoscopist's body is well protected by a lead apron, there can also be substantial doses to unshielded parts. Average doses to the eyes in range of 0.1–1.7 mGy per procedure and doses of about 0.5 mGy to the hands have been reported. Doses to assisting personnel are usually a few factors lower, depending on position and the time spent near the x-ray source, as they usually stand further away from the patient.

3 Effects of radiation

X-rays consist of ionizing radiation, such as gamma rays or other types of radiation emitted by radioactive substances. They cause ionization in the medium through which they pass. The ionization produced can lead to damage in DNA or cell death. The issue of the effects of radiation requires explanation, as it is often either fear of radiation or complacency that guides the perception of risk, rather than the actual radiation risk or effect.

Radiation effects are broadly divided into two categories: *deterministic effects,* such as cataract formation, infertility, skin injury, and hair loss; and *stochastic effects* (cancer and genetic effects). The deterministic effects (primarily cataract and hair loss) have been documented by interventional radiologists and interventional cardiologists. There are no reports of such effects in gastroenterologists. The amount of radiation currently being used by gastroenterologists is relatively small in comparison with interventional radiologists and interventional cardiologists.

The harm depends on the amount of radiation absorbed in the human body, known as the radiation dose or simply "dose." While deterministic effects have a threshold, stochastic effects can occur at any level of radiation exposure, however small. The principle governing stochastic effects is that the probability of effects is proportional to the radiation dose. On the basis of this, international organizations have agreed on the principle of "as low as reasonably achievable" (ALARA). This does not imply that carcinogenic or hereditary effects will definitely occur at lower levels of radiation (doses of a few millisieverts per year). It is like the risk of meeting with an accident while crossing the road. The more often one crosses, the more likely it is that an accident may happen. One may cross 100 times without having an accident, but the likelihood increases with each crossing. It is in light of this that the ALARA principle becomes important.

It is not possible to document radiation effects at the level to which gastroenterologists performing ERCP or fluoroscopy are exposed—typically whole-body effective doses of 0–3 mSv/year when appropriate radiation protection tools and principles are applied. The dose limit that is recommended by the International Commission on Radiological Protection (ICRP) and adopted by most countries is 20 mSv/year. For situations in which the annual dose limit exceeds 20 mSv, it is recommended that the dose should not exceed 50 mSv in any particular year or 100 mSv over 5 years. This dose limit is based on the calculation of radiation risk over a full working life from the age of 18 years to 65 years (47 years) at the rate of 20 mSv per year, amounting to 20 × 47 = 940 mSv (approximately 1 Sv) and resulting in an excess cancer risk of one in 1000 over and above the natural incidence of cancer.

4 Radiation protection for staff and patients

Gastroenterologists may ask whether it is possible to work for one's entire professional life with radiation without suffering any radiation effects. The answer is yes, it is possible—in optimized conditions, when:

- The equipment is periodically tested and is operating properly.
- Using personal protective devices (apron with a suitable lead equivalence of 0.25–0.35 mm and of the wrap-around type, thyroid shield, protective eyewear, or protective shields for the head/face and leg region). On the basis of recent data, it is now being recognized that protecting the eyes against cataract formation is more important than was previously thought.
- Personnel monitoring devices are used to estimate radiation exposure.
- Proper technique is used, as discussed below.

While hands can tolerate more radiation (500 mSv per year as the dose limit), it is best practice to keep the hands out of the primary radiation beam, rather than wearing lead gloves.

There are situations in which patient protection may pose a considerable challenge. Until only some 10 years ago, radiation protection programs were largely determined by concerns for staff protection. Most countries have adopted a system in which it is mandatory to monitor the radiation dosage to the staff working with radiation and to keep lifetime records of the dosage. Patient protection was thought to be less important, on the false assumption that patients undergo examination with ionizing radiation only a few times during their lifetime. It was always thought that the concept of dose limitation did not apply to patients, as it was important not to constrain the associated medical benefits of using radiation. However, cases of radiation injury, particularly to patients' skin, have been documented among those undergoing interventional procedures in cardiology and radiology that require extended fluoroscopy periods (1 h or more), or those receiving repeated procedures at the same site. Patient protection is now becoming more important, as it has been recognized that there is a potential for much higher radiation exposure to patients, who may receive more radiation during a few computed tomography (CT) scans than a member of staff may have in a whole lifetime.

The early emphasis on staff protection did improve staff safety. Data presented by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) show that the average effective radiation dose received by those working with ionizing radiation in medical practice is typically below 2 mSv per year [1]. This is lower than what people receive from natural radiation sources, known as background radiation (e.g., from cosmic radiation, radon, radiation from building materials, earth, food). The background radiation depends on a number of factors, mainly involving the place of residence. The global average dose is 2.4 mSv per year, but it may be as high as 10 mSv per year in a few places where there are known to be larger deposits of radioactive substances in the earth, and depending on the local level of radon.

The radiation dose to the patient depends on a number of factors, including those listed below.

Patient factors

- Body mass or the thickness of the part of the body lying in the x-ray beam. Patients in whom a larger thickness is located within the beam require higher doses in order to allow quality images.
- Young age. Tissues in pediatric patients (including thyroid, gonads, and breasts) are much more susceptible to the damaging effects of radiation in comparison with adults.
- The patient's disease and the indication for the procedure. Complex diagnoses and those that are likely to subject the patient to challenging therapeutic interventions are associated with higher doses.
- Previous radiation exposure. This may increase the risk of radiation injury.
- Radiosensitivity in some patients (e.g., those with ataxia–telangiectasia), connective-tissue disease (discoid lupus), and diabetes mellitus.

Equipment factors

- Manufacturers' settings for fluoroscopic dose rates.
- The position of the x-ray source relative to the patient and staff. Placing the x-ray tube below the patient (undercouch) subjects the staff to less scattered radiation.
- Pulse frequency. Lower pulse rates (such as 7.5 or 15 frames per second) produce lower overall radiation doses per procedure.
- Appropriate quality control. Properly functioning fluoroscopic equipment and personnel protection equipment is an important component of radiation safety.
- The image-holding and image capture function. This allows the user to spend time reviewing the fluoroscopic image without the need for continuous x-ray exposure.
- Alarm levels for time and higher dose rates in fluoroscopy. These serve as effective reminders to limit fluoroscopy to the shortest time possible.
- The use of digital x-ray machines. While these newer devices are capable of reducing radiation doses, they may be associated with higher radiation doses due to increase in image clarity without recognizable over exposure.

Procedure-related factors

- Fluoroscopy time
- Collimation, to reduce the area of exposure
- Number of radiographic images obtained
- Magnification
- Distance between the patient and the image receptor (image intensifier or flat-panel detector)
- Distance between the x-ray tube and the patient, and tube angulation

The patient dose can be minimized by optimizing the factors listed above while maintaining the highest-quality image required for a successful procedure. Specifically, the recommended steps include:

- Increasing the distance between the x-ray tube and the patient
- Keeping the image receptor as close to the patient as possible

- Keeping the foot on the pedal only when essential
- Reducing the number of images acquired (runs)
- Collimating the x-ray beam
- Using pulsed fluoroscopy
- Avoiding magnification
- Reducing exposure to radiosensitive organs such as the breast
- Reducing oblique views

5 Cascades: management options taking available resources into account

Radiation protection is as important in modern facilities as in facilities with older equipment. It is essential to take an adequate patient history, evaluating previous radiological procedures, radiosensitivity history, and other factors that may influence radiation exposure. In all circumstances, application of the ALARA concept is required. The levels listed below provide management options relative to available resources.

Level 1: high resource levels

- Licensing by the appropriate radiation regulatory authority
- Regular and periodic quality-control testing of equipment and protective devices to maintain optimal performance
- Last image capture, use of pulsed fluoroscopy at an optimized pulse rate
- Personal protective devices such as aprons, lead glass eyewear, thyroid shield, lead flaps and screens
- Proper use of personnel dosimetry badges by all staff
- Participation in an institutional radiation safety program
- Staff standing at the side of the image receptor rather than at the side of the x-ray source, maximizing the distance between staff and the radiation source
- Use of proper technique to minimize the radiation dose to the patient (e.g., keeping the x-ray tube as far away from the patient as possible and the image receptor as close as feasible, collimation, lower magnification)
- Recording of radiation exposure factors for the patient—fluoroscopy time and the product of dose and area, known as the dose–area product (DAP)
- Ensuring that staff members are aware of radiation doses to themselves and to patients through training, particularly of new staff
- Accreditation by the appropriate professional body

Level 2: average resource levels

- Licensing by the appropriate radiation regulatory authority
- Staff protective devices (lead apron)
- Proper use of staff dosimetry badges by the main operator
- Staff standing at the side of the image receptor rather than at the side of the x-ray source, maximizing the distance between staff and the radiation source

- Use of proper technique to minimize the radiation dose to the patient (e.g., keeping the x-ray tube as far away from the patient as possible and the image receptor as close as feasible, collimation, lower magnification)
- Recording of radiation exposure factors for the patient—fluoroscopy time and the product of dose and area, known as the dose–area product (DAP)
- Ensuring that staff members are aware of radiation doses to themselves and to patients through training, particularly of new staff

Level 3: minimum resource levels

- Licensing by the appropriate radiation regulatory authority
- Personal protective devices (lead apron)
- Staff standing at the side of the image receptor rather than at the side of the x-ray source, maximizing the distance between staff and the radiation source
- Use of proper technique to minimize the radiation dose to the patient (e.g., keeping the x-ray tube as far away from the patient as possible and the image receptor as close as feasible, collimation, lower magnification)
- Recording of radiation exposure factors for the patient (fluoroscopy time)
- Ensuring that staff members are aware of radiation doses to themselves and to patients through training, particularly of new staff

6 Special circumstances

Pregnancy

When a pregnant patient requires ERCP for therapy, the procedure should be optimized by strict adherence to good technique, as described above. In addition, if there is a possibility that the primary x-ray beam may intercept the fetus, placing a lead apron between the x-ray source and the fetus is effective. For the proportion of fetal radiation exposure resulting from radiation that is scattered inside the patient's body, protection by a lead apron placed externally is ineffective. The patient's position (supine, prone, or lateral) should be adjusted to minimize fetal exposure [2]. A posteroanterior projection of the x-ray beam is recommended, as this results in a fetal dose that is 20–30% lower than in the anteroposterior projection due to increased shielding from the mother's tissues. The lateral projection also provides increased fetal shielding, but the patient's entrance dose rate may be three to seven times higher in comparison with a frontal projection. As a result, the lateral projection results in a higher fetal dose [2].

An alternative technique, avoiding radiation exposure completely, involves conducting ERCP without fluoroscopy, using wire-guided cannulation techniques. Choledochoscopy can be used to confirm stone clearance. However, this approach is technically challenging and has only been used by very experienced biliary endoscopists.

Children

All of the recommendations given above apply, and special emphasis needs to be given to protecting the thyroid and protecting the breast in young girls, by shielding or beam adjustment wherever feasible.

7 Appendix: radiation quantities and units

Absorbed dose is the energy absorbed per unit mass at a given point. It is expressed as joules per kilogram (J kg^{-1}), representing the SI unit gray (Gy). A more detailed description is given in ICRU Report 74 [3] and in IAEA Technical Report 457 [4].

Organ dose is a quantity defined by the ICRP [5,6] in relation to the probability of stochastic effects (mainly cancer induction) as the absorbed dose averaged over an organ—i.e., the quotient of the total energy imparted to the organ and the total mass of the organ. It is expressed as joules per kilogram (J kg^{-1}), representing the SI unit gray (Gy).

Dose equivalent. The equivalent dose to an organ or tissue is the organ dose corrected by a radiation weighting factor that takes account of the relative biological effectiveness of the incident radiation in producing stochastic effects. This correction factor is numerically 1 for x-rays. It is expressed as joules per kilogram (J kg^{-1}), representing the SI unit sievert (Sv).

Effective dose is a quantity defined by the ICRP [5,6] as a weighted sum of equivalent doses to all relevant tissues and organs, intended “to indicate the combination of different doses to several different tissues in a way that is likely to correlate well with the total of the stochastic effects.” This is therefore applicable even if the absorbed dose distribution over the human body is not homogeneous. It is expressed as joules per kilogram (J kg^{-1}), representing the SI unit sievert (Sv).

The effective dose for patients has to be used with caution, as indicated in the UNSCEAR 2000 report to the UN:

> The Committee has always indicated … that these effective doses should not be used directly for estimating detriment (to individuals or populations) from medical exposures by application, for example, of the nominal fatality probability coefficients given by ICRP … Such assessments would be inappropriate and serve no purpose in view of the uncertainties arising from potential demographic differences (in terms of health status, age, and sex) between particular populations of patients and those general populations for whom the ICRP derived the risk coefficients. It has been suggested, for example, that effective dose could broadly underestimate the detriment from diagnostic exposures of young patients by a factor of about 2 and, conversely, could overestimate the detriment from the exposure of old patients by a factor of at least 5 … Notwithstanding the above caveat, practice in diagnostic radiology is summarized in this Annex, for comparative purposes, principally in terms of effective doses to exposed individuals undergoing each type of procedure and, taking into account numbers of procedures, collective effective doses over exposed populations [ref. 1, pp. 296–7].

It is therefore possible to use effective dose and even collective dose to assess medical diagnostic exposure, as long as this is done only for comparative purposes and for the same or similar patient populations. It would require additional considerations or significant corrections if it were used for comparison with other populations.

Air kerma is the sum of the kinetic energy of all charged particles released per unit mass. A number of earlier publications have expressed measurements in terms of the absorbed dose to air. Recent publications and a forthcoming IAEA Code of Practice point out the experimental difficulty in determining the dose to air, especially in the vicinity of an interface; in reality, what the dosimetry equipment registers is not the energy absorbed from the radiation by the air, but the energy transferred by the radiation to the charged particles resulting from the ionization. For these reasons, the IAEA Code of Practice and ICRU Report 74 recommend the use of air kerma rather than absorbed dose to air. The unit is joules per kilogram ($J\ kg^{-1}$), representing the SI unit gray (Gy).

This correction applies to quantities determined in air, such as the entrance surface air kerma (rather than entrance surface air dose), the computed tomography air kerma index (instead of computed tomography dose index), the kerma area product (rather than dose–area product) and the air kerma area length (rather than dose–length product).

The above recommendation refers to air. When referring to tissues, it is also correct to estimate the absorbed dose to the skin by applying the necessary correction coefficient to obtain the absorbed dose to the tissue from the air kerma.

Collective dose is a measure of the total amount of effective dose multiplied by the size of the exposed population. Collective dose is usually measured in units of person-sieverts.

8 References

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