PRACTICAL ASPECTS OF RADIATION PROTECTION IN INTERVENTIONAL RADIOLOGY

K. Faulkner[1], E. Vañó[2], P. Ortiz[3], R. Ruiz[4].
[1]Newcastle General Hospital, [2]Universidad Complutense de Madrid, [3]International Atomic Energy Agency, [4]Universidad de Málaga.

ABSTRACT

The rise in the frequency of interventional procedures over recent years is due to the significant benefits of interventional radiology. Patients may be treated as an out-patient for clinical conditions, which would have otherwise needed surgery, i.e., a more traumatic and expensive treatment. In some circumstances, for example in neuroradiology the aneurysm may be inoperable surgically and interventional radiology is the only method of treatment. The growth in interventional radiology therefore reflects a drive towards better, safer and more cost effective medicine. Certain types of interventional radiology procedures are quite complicated and may involve the use of extended fluoroscopy times and the use of high dose rates. In some cases reappearance of the original disease, such as restenosis, may lead to repeated interventions. This combination together with a lack of quality control in x-ray systems, has led deterministic effects in the skin of patients ranging from transient erythema to necrosis. In a few cases, staff doses reached the levels of deterministic effects, such as dot-like sub-capsular opacities (cataracts) and small dot-like paranuclear opacities and discrete posterior sub-capsular condensations in both eyes.

A review of the reported cases of deterministic effects reveals that the working conditions in those cases were extreme. From these lessons, measures for preventing deterministic effects are straightforward and are given in this paper. In addition to these straightforward measures, a more comprehensive approach includes review of technical factors used in protocols and exploratory research of the potential for dose guidance (reference) levels as a tool for optimization.

BACKGROUND

One of the major growth areas in radiology and high technology medicine has been the field of interventional radiology. In some respects this increase has been in part due to the substantial improvements in imaging performance of x-ray equipment and refinements in catheter design in recent years. These equipment and catheter design improvements have had significant implications for interventional radiology, by enabling the techniques to become available to a wider number of centres. The patient benefits and financial savings associated with the treatment of some pathologies are the main causes for the increase of the frequency, nature and complexity of interventional radiology. The increased expectations of interventionalists is likely to place additional demands on x-ray equipment and catheter manufacturers. In addition, there is considerable public pressure for more access to these procedures because they understand the benefit they receive.

The development of the balloon catheter and stents for performing and maintaining artery dilatation[44] has precipitated a dramatic increase in the frequency of interventional radiology. Equipment developments and the drive for safer, cost-effective medicine had led to the extensive application of interventional radiology. Interventional radiology results in better treatments for the patient without the need for general anaesthesia or occupying intensive care beds following the procedures (1).

Zeitler (1) gives a useful definition of interventional radiology, '*The term interventional radiology comprises interventions on diseased persons, in whom either the pathological changes causing the symptoms are being removed or improved, thus moderating their effects, or progression of the disease is being stopped or at least slowed down. This is done via a percutaneous access, without opening of a body cavity mainly under local anaesthesia. In the framework of these interventions x-rays are used prior to the intervention - for precise localisation of the lesion, - for monitoring of the procedure, and finally for the control of the outcome. The pre-treatment and follow-up control is in many cases done by means of a selective angiography in two or more projections."*

Gunther et al (2) has classified interventional radiology procedures as either diagnostic or therapeutic. Interventional radiology may also be classified according to anatomical region. Interventional procedures may be further subdivided into vascular and non-vascular procedures (2).

REVIEW OF REPORTED DETERMINISTIC EFFECTS

Effects on Patients

A number of cases of deterministic effects arising from interventional radiology have been reported (3-18). At the 1995 meeting of the Radiological Society of North America, a review of radiation induced skin injuries from fluoroscopy by the US Food and Drug Administration (FDA), was presented. After the initial report to officers of the FDA, it followed it up with a series of telephone calls, letters and visits to the facility to obtain more detailed information. Table 1 summarises the reports received by the FDA (17). It may be deduced from Table 1 that over half the skin injuries occurred following either radiofrequency (RF) ablations or coronary angioplasty, though it is apparent from Table 1 that many types of interventional procedures have the potential to result in skin injury.

TABLE 1. REPORTS RECEIVED BY FDA OF SKIN INJURY FROM FLUOROSCOPY (17)

Type of Procedure with Injury Report	Number of Injuries Reported
RF cardiac catheter ablation	13
Catheter placement for chemotherapy	1
Transjugular interhepatic portosystemic shunt (TIPS)	3
Coronary angioplasty	4
Renal angioplasty	2
Multiple hepatic/biliary procedures	3
Percutaneous cholangiogram with multiple embolisations	1

TABLE 2. EXAMPLES OF SKIN INJURIES FROM FLUOROSCOPY(17)

Patient	Sex	Age	Procedure	Injury
A	Male	40	Coronary angiography & PTCA, followed by second coronary angiography	Skin necrosis requiring 12x10 cm skin graft
B	Female		RF catheter ablation	Second degree burn(7.5x12.5 cm)
C	Female	25	RF catheter ablation	Skin breakdown 3 weeks post procedure
D	Female	34	RF catheter ablation	Draining skin lesions on back 3 weeks after procedure
E	Female	62	Balloon ablation bile duct	Burn-like injury on back anastomosis requiring a skin graft
F	Female	61	Renal angioplasty	Skin necrosis requiring graft

Skin injuries from fluoroscopy guided procedures, investigated in depth by the FDA (17) are reported in Table 2. In the main, cardiac procedures have the most complete reports on them. Patient A, who was a 40 year-old male, had a series of cardiac interventional procedures. These comprised a coronary angiography, a coronary angioplasty procedure, another coronary angiography and a coronary artery by-pass graft on the same day (17). Skin injuries to this patient got progressively worse over a period of 18 to 21 months, at which time tissue necrosis was evident. The deterministic injury to the patient's back was treated by skin grafting.

Widmark and Hellesnes reported a case of a severe radiation burn following a percutaneous transluminal coronary angioplasty (PTCA) procedure (19). The patient was a 58 year-old male who had two stenoses. One of the stenoses was successfully dilated during the PTCA procedure, the other was not dilated successfully despite several attempts. Unusually for a PTCA procedure, a single projection was mainly used for 50 minutes out of a total of 68 minutes fluoroscopy time. Approximately 80% of the total time for this single projection was performed in high dose or boost mode. In addition 34 seconds of cinefluorography was performed at a frame rate of 50/second. The PTCA procedure was simulated on an Alderson Rando anthropomorphic phantom. Lithium fluoride thermoluminescent dosemeters (TLD) were used to assess the surface dose in the region which was thought to receive the highest dose (ie: the right scapula). The measured surface dose was approximately 16 Gy. Three weeks after the PTCA procedure, the patient developed a severe skin burn, with a diameter of 7 cm. This skin burn subsequently ulcerated.

Recently Vañó et al (20) reported a series of patients in whom deterministic skin injuries had been observed following radiofrequency ablation cardiac interventional procedures. In the main erythematous lesions and chronic radiodermatitis were observed. Once again, the procedures were performed using mainly one set of projection directions on a bi-plane fluoroscopy system designed specifically for cardiac applications (see figures 1 and 2). Moreover, the bi-plane projection directions were fixed. The skin entrance dose was particularly high for the lateral projection as the focus skin distance used was less than that recommended by ICRP, publication 34 (21). Skin entrance doses in the range 11-15 Gy per procedure were reported (20).

FIGURE 1

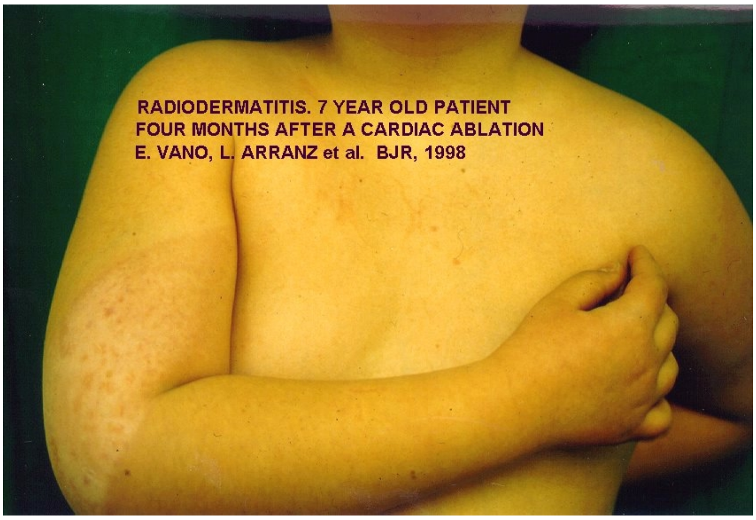


Figure 1 is a photograph of a 7 year-old patient with radiodermatitis in the right arm (20). Deterministic injuries in a 17 year-old patient are illustrated in Figure 2 (20). The patient had two RF cardiac ablation procedures two years previously. This patient has reduced motility in the right arm as well as chronic radiodermatitis and atrophic indurated plaque.

FIGURE 2

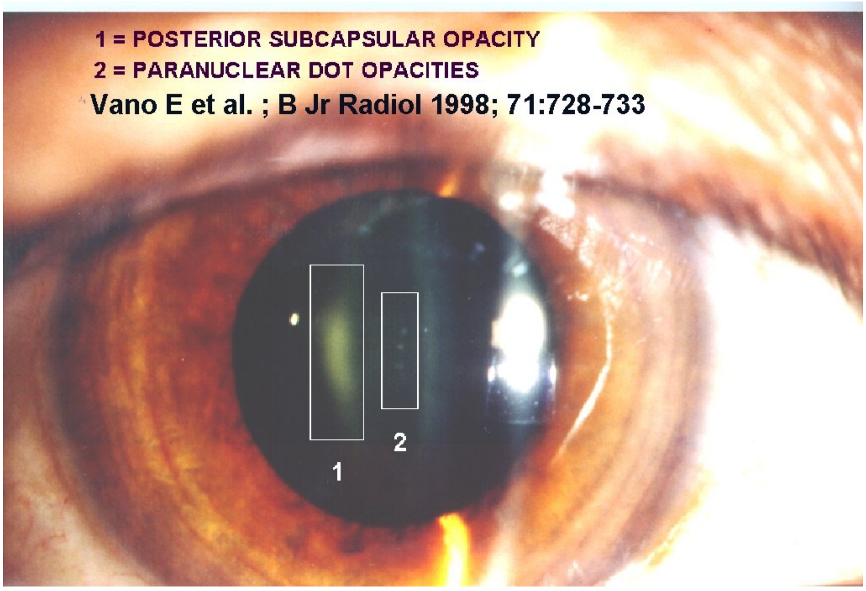
From the above it can be concluded that certain types of interventional radiology procedures are quite complicated and may involve the use of extended fluoroscopy times. The combination of extended fluoroscopy times and the high dose rates often necessary for imaging in interventional radiology may result in the deterministic effects in the skin in particular. Skin effects observed in patients range from transient erythema to necrosis. This provides an indication of the magnitude of some of the doses received by some patients. Even if the skin dose from a single procedure lies below the threshold for skin effects, consideration has to be given to the fact that a significant number of patients will require one or more repeat procedures because of restenosis, and therefore he/she will be exposed to x rays again.

Effects on Staff

Staff are generally exposed only to scattered radiation and to leakage radiation from the x-ray tube. Scattered radiation dose-rates at the couch side during fluoroscopy procedures are usually quite low (of the order of 1/100 to 1/1000, depending on the distance to the patient's irradiated volume) compared with patient skin dose rates. However, the combination of high dose-rates, together with a large interventional radiology workload with extended fluoroscopy times, may result in the interventionalist receiving a high eye dose if protective equipment is not used. This is aggravated for certain types of fluoroscopy equipment, (e.g. over-couch tube/under-couch image intensifier units, from which deterministic effects in the eyes of the staff have been observed resulting from doses accumulated over 4 years (22). The reported cases involve lens opacities observed in staff working at two Spanish Hospitals. Interventional radiology was performed in rooms not specifically designed for the purpose. Both rooms had equipment with an over-couch tube/under-couch image intensifier configuration without ceiling suspended lead protection. Lens opacities were observed in one radiologist and two nurses. The opacities were considered to have been caused by radiation in the opinion of the ophthalmologist who examined them. Scattered radiation dose-rates in the vicinity of the patient at the positions usually occupied by staff were sufficiently high to exceed the threshold for the induction of lens opacities for typical workloads. The ophthalmologist diagnosed dot-like subcapsullar opacities (cataracts), consistent with radiation damage from ionising radiation

In another centre, an interventional physician who had worked several years in a room with equipment similar to that referred to above, underwent an opthalmic examination. Biomicroscopic analysis revealed the presence of small dot-like paranuclear opacities and discrete posterior subcapsular condensations in both eyes (see figure 3). For the two radiologists affected a retrospective dose estimation was performed. Estimated eye lens doses were 450 mSv and 900 mSv/year. The radiologists had received these annual doses over a period of several years.

FIGURE 3



LESSONS LEARNED

Lessons learned from the effects on Patients

When analysing the causes and reasons for these over-exposure incidents to patients it is possible to draw a number of conclusions. Most of the reported incidents have their origins in one or more of the following:

1. the x ray tube was too close to the patient,
2. there was an excessive and inappropriate use of the high dose-rate mode
3. a fixed beam projection was used (radiation entering through the same skin surface all the time)
4. there was a malfunction of the automatic exposure control system

The four items above had as root causes the lack of knowledge on radiation protection and of a programme of quality assurance

Lessons from the effects on staff

For staff working in interventional radiology, opacities of eye lenses and even cataracts can occur if the individual has a high workload and the dose rates at the couch side are high. This has been aggravated by the use of conventional equipment with over couch x-ray tube for interventional procedures and a lack of training on radiation protection. It is therefore important to use dedicated equipment and protective means such as glasses and screens whenever compatible with the intervention, when they are available or have them fitted to equipment if they are not present.

Interventional radiology and potential exposure

In interventional radiology, skin injuries could be considered normal exposures when they can be anticipated and accepted in advance, i.e., when the patient pathology may demand long fluoroscopy time or repeated interventions in a short time interval (as the one required in the case of restenosis), and the best choice is to accept them and to optimize protection of the procedure.

However, practically all cases of deterministic effects described to date in the scientific literature for interventional procedures have many of the characteristics of potential exposures: wrong operation of the equipment (higher dose rates than those necessary), or procedural errors (excessively long time at high dose rate, i.e. high contrast-low noise fluoroscopy, collimator too close to the patient skin, etc), that are also derived in part from an incomplete training in radiation protection of the specialists accomplishing the procedures. These events could have been prevented, protective measures of optimization could have been taken, and the procedure could have been performed without severe radiation injuries.

PRACTICAL ADVICE ON DOSIMETRY

The objectives of a system of radiation protection in general, is to prevent deterministic effects and to reduce the likelihood of stochastic effects. Therefore, the strategy of dose monitoring in interventional radiology serves two purposes: 1) to find out which areas of the body might receive doses that are comparable with thresholds for deterministic effects in order to keep the radiation dose to them under control; the quantity related to this purpose is the absorbed dose to the most exposed area and 2) to evaluate the quantities related to stochastic effects, in order to keep them as low as reasonably achievable; the quantity related to the overall probability of stochastic effects is the effective dose, which can be obtained from the equivalent dose to the relevant tissues, or estimated from the energy imparted

Due to the many parameters involved in interventional procedures, the different operational modes and, therefore, the large number of possible combination of these factors, the determination of the values of these quantities not easy.

Practical strategy dosimetry of the patient

A first and pragmatic approach to a rough patient dose estimation, is to record the total fluoroscopy time and number of images. This approach should be used for a certain number of patients and procedures if more complete methods are not available initially in some installations.

Three levels of information could be considered (see figure 4):

- i the first one (more simple but also with limited information) with fluoroscopy time and number of images;
- ii a second one, includes additional quality control information, such as dose rate at the entrance of a phantom and dose/image for cine or for digital recording, complemented with the indication of the irradiated patient area, and
- iii a third one, with the most complete information, dose-area product (DAP) and entrance-surface dose (ESD). Fig. 4 presents some examples of data obtained for Percutaneous Transluminal Coronario Angioplasty (PTCA) (23). This information can be derived in each of three levels: the clinical protocol is related basically with the number of images and fluoroscopy time per procedure; dose rate and dose/image are more related with equipment and image intensifier performance, and patient dose allows the evaluation of stochastic and deterministic risks.

Dosimetry of staff

Staff performing interventional radiology may receive substantial doses which may approach some of the dose limits if their workload is high and their caseload involves extended fluoroscopy times, especially if inappropriate equipment is used or when protective measures are not taken. The critical group comprises staff who stand at the couch side during interventional radiology procedures and who have a high patient workload of procedures with extended fluoroscopy times.

It is suggested that individuals working in interventional radiology wear two dosemeters, one under the apron and another above the apron); the combination of both dosemeters can be used to estimate the effective dose. Combining the two readings can yield an improved estimate of the effective dose (24). The combination formula to obtain the effective dose estimate is:

$$E(\text{estimate}) = 0.5\ HW + 0.025\ HN$$

Where HW is the dose recorded by a dosemeter worn at waist level under the lead apron and HN is the dose recorded by a dosemeter worn at neck level above the apron.

The unshielded dose meter can be additionally used to estimate the dose to the lens of the interventionalist. An additional finger dosemeter may be advisable, especially if the hands may be close to the direct beam.

As mentioned above, occupational dose limits may be exceeded in certain, less than optimal circumstances in interventional radiology. Imposing restrictions to the conditions of work without a thorough investigation may bring more harm than benefit, and in the absence of a solution, it may encourage people to hide their dose meter as an avoidance measure. When doses are considered likely to exceed to dose limits, it is recommended to undertake a dose survey, in co-operation with the interventionalist, and to closely observe the way procedures are performed to find out the reasons and ways to reduce dose without impairing the procedure. A complete knowledge of the cause for the high dose can improve work practices and help thereby meet regulatory requirements.

Summary of doses

During recent years an number papers reporting patient and staff doses in interventional radiology have been published. Due to the large number of factors affecting the dose values there is a wide range of variation. A summary of the most relevant data is given in table 3.

TABLE 3. SUMMARY OF REPORTED DOSES TO PATIENTS

	Type of intervention	**Quantity measured**	**Values**
Betsou et al. (1998) (25)	coronario angiography (CA)	DAP	37,6to 50,6 Gy.cm2
	PTCA	DAP	37,6 to 50,6 Gy.cm2
	Stent implantation	DAP	49,2 to 70,7 Gy.cm2
Broadhead et al. (1997) (26)	coronario angiography (CA)	DAP	23,4 to 47,7 Gy.cm2
	PTCA	DAP	51,6 to 72,2 Gy.cm2
Vañó et al. (1995) (27	coronario angiography (CA)	DAP	25, 3 to 66,5 Gy.cm2
	coronario angiography (CA)	skin dose	113 mGy
	PTCA.	DAP	81,7 to 87,5 Gy.cm2
McParland (1998) (28	Cerebral Embolization	skin dose	160 to 180 mGy
	Biliary stent	DAP	27,9 Gy.cm2,
	Biliary stent	skin dose	110 mGy
	Nephrostomy)	DAP	24,2 Gy.cm2
	Nephrostomy	skin doses	110 mGy
	TIPS	DAP	347 Gy.cm2)
Vano et al. (1997) (29)	TIPS	DAP	353,7 cGy-cm2 for
	hepatic embolization	DAP	81,7 Gy.cm2
	biliary drainage	DAP	68,9 Gy.cm2

Occupational doses measured on the shoulder of cardiologists have been reported to be in the range of 0,3 to 0,5 mSv per cardiological procedure; these values correspond to about 10 μSv per Gy.cm2 received by the patient (30). Old x-ray systems used without protection for the interventionalist have led to 450-900 mSv per year at the eyes of the interventionalist, as estimated by Vano et al (22), with the result of lens injuries (opacities). A wide range of staff doses in interventional procedures have been reported: 0,3-0,4 mSv/procedure to the face and neck (31), a neck dose of 0,05 mGy/procedure (32), 0,22-0,37 mSv/procedure at thyroid level (33), and 0,28 mSv/procedure in left eye (34).

The complexity of the procedures, the large number of parameters influencing the dose and the wide range of dose values obtained, indicate the need for systematic research, and a methodology for evaluation in order to be able to identify a correlation between doses and factor influencing doses.

PRACTICAL RECOMMENDATIONS

The case studies above have shown that severe deterministic effects on patients, such as ulceration and skin necrosis, only have occurred under extreme working conditions. The lessons from these case studies showed that these conditions were mainly: a) very short distance from x-ray focus to the patient, collimator in direct contact with the skin, b) use of high dose rate mode for a time much longer than necessary, c) fixed projection exposing the same area of skin and d) malfunction of automatic exposure control systems.

From these lessons, the following straightforward measures for preventing deterministic effects are recommended: a) placing the x-ray tube at a distance of 50 cm or more from the skin whenever possible, b) placing the image intensifier as close as possible to the patient, c) making selective use of high dose rate mode, by prior identification situations in which this use is really necessary, d) changing the projection where necessary and possible, and d) performing simple constancy checks to detect malfunctions in the automatic control systems.

Consideration should also be given to the fact that, for a significant number of patients the procedure is repeated, in many cases several times (see section on deterministic effects). Therefore a more comprehensive approach including control of doses and optimization of protection should achieve that doses in a single procedure are kept at the level of a fraction of the threshold dose for severe deterministic effects and that the probability of stochastic effects is kept to a minimum compatible with the objectives of the procedure.

Clinical procedure

Referral criteria.

Given the need to avoid radiation injuries and in many centres the pressure of the interventional radiology workload, it is important to establish appropriate referral criteria for interventional radiology. Whilst referral criteria have been established for some examinations, in general, no consensus has evolved for interventional procedures. As circumstances vary between centres, referral may be influenced by local demands for interventional procedures and the availability of other interventional facilities locally. For these reasons a consensus and general advice by professional societies would be very beneficial.

Planning and preparing the procedure.

The initial means of avoiding deterministic effects in interventional radiology is by carefully planning and preparing the clinical procedure. The projections and beam features, as well as the most exposed skin area and the potential for deterministic effects should be anticipated as far as practicable using previous experience with similar cases. Consideration should be given to possible clinical complications of the procedure and their impact on the radiation exposure of the patient and possible deterministic effects and to repetition of procedures on the same patient.

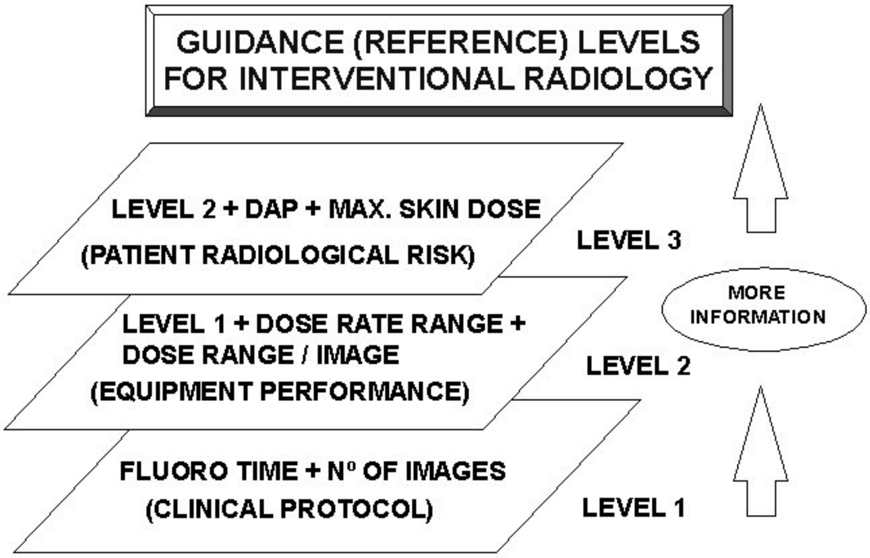
Protocols

Interventional procedures vary from one case to the other. A large range of radiation doses can be found among procedures, which might appear to be similar in principle. As an example, the dilatation of a stenosis in a specific part of a coronary vessel can be extremely difficult if some "tortuosity" is found when trying to arrive with the catheter at the desired location. However, it is possible to predefine predominant patient-beam projections, and by comparison, systematically analyze the effect of complications and deviations from these conditions on the radiation dose, and to train the staff and plan for these conditions. Protocolling these conditions would facilitate the preparation, planning, and dose assessment and provision for dose reduction; comparison studies are more efficient, completeness is ensured and radiation dose can be reduced.

Guidance or reference levels

Guidance or reference levels have been used for common examinations as a reasonable indication of doses for average sized patients. These levels are associated with standardized technical factors for common and simple examinations and should only be used in conjunction with the evaluation of the image information. The application of this approach of using guidance levels to interventional radiology is not straightforward due to the complexity of interventional procedures. However, guidance or reference levels can be developed and used to assess equipment performance (dose rate and dose per image), and to optimize protocols (fluoroscopy time, total number of images per procedure, and dose-area product). However, in interventional radiology, considerable tolerances in the values are required to allow for variations for patient size, pathology and complications. See figure 4.

FIGURE 4



Customizing equipment settings

Equipment for interventional procedures offers a wide variety of parameter selection options. Dedicated user procedures often need to be customised. The demands on image quality for some procedures, projections and tools (eg balloon or stent catheter) may require different dose levels. Difficult stent positioning and heavy patients may require higher dose rate for a limited time.

Training

Interventionalists, qualified experts in diagnostic imaging physics, technologists and maintenance engineers need an understanding of patient dose levels, the possibility of deterministic and stochastic effects, methods for patient dose reduction and lessons learned from case histories, as well as on the different operation modes and the criteria to use them in the different phases of the procedure.

Quality assurance

A comprehensive quality assurance programme should be developed to encompass all aspects of how the patient is dealt with within the department. Technical operation of the equipment is tested by quality control procedures. Because of the complexity of equipment used in interventional radiology, quality control of the many parameters involved is time consuming and a careful selection of the parameters to be controlled in constancy checks and frequency are essential parts of the programme. A strategy is therefore needed. An example of this strategy is given in the DIMOND approach (35)

Technical factors relevant to image quality and radiation dose

The effects of the multiple technical factors are complex and cannot be given in detail in this paper. Table 4 stresses the most obvious relationships but is not comprehensive. More detail is given in 36.

TABLE 4. INFLUENCE OF TECHNICAL FACTORS

Positioning	Increasing the focus-skin distance reduces the skin dose. Changing projection angle when compatible with the procedure, changes the surface being exposed and therefore, also reduces the skin dose.
Field size	Reduction of field size improves image quality and reduces the exposed volume. It can also reduce the dose to the most exposed area, when combined with changing projection (reduces overlapping)
X-ray spectrum	Increasing the “penetration of the beam” (mainly through filtration and tube potential) reduces skin dose but also influences the image contrast. The beam spectrum should be optimized to obtain the desired contrast with the minimum radiation dose..
Automatic dose or brightness control (ABC) for fluoroscopy	Proper flouro-mode selection provides the optimum image with only the necessary dose (image contrast and noise). Pulsed fluoroscopy can save radiation dose, the amount of reduction being dependent on the pulse frequency that can be accepted, i.e., depending on the type of intervention. Last image hold reduces the time in which the beam is “on”, by observing a stored image.
Automatic exposure control (AEC) for fluorography	The dose per frame and the total number of frames are proportional to the dose received by the patient. The total number of frames depends on the frequency (images/second) and the time of the scene: both of them can be optimized to the needs of the procedure.
Wedge filters	Edge filters provide a smooth transition over the patient tissue (for example at extremities) and can reduce the dose to certain areas of the patients. The wedge should not shadow the sensor of the automatic brightness control
Post patient attenuation	Absorption between patient exit and image receptor (couch, grid, external entrance layer covering image detector), leads to increases the dose the patient, in order to maintain the dose to image receptor constant. Therefore reducing absorption by these parts reduces also patient dose.
Scattered radiation	When small volumes (little scatter) are irradiated, removal of antiscatter grids reduces dose. Digital post processing removing contribution of scatter radiation from the image has a potential for dose reduction in future
Image receptor	High conversion factors for image intensifiers is indispensable in interventional radiology. Use of smaller format of the image intensifier (magnification) and maintaining the image noise at the same level, implies an increase of skin dose to the exposed area.
Digital image acquisition	Digital imaging allows images, acquired at any dose, to be displayed at an acceptable contrast and brightness. However, the limiting factor in dose reduction is the image noise.
Computational methods (image post-processing)	Post processing can reduce image noise by temporal or spatial averaging. This may result in dose reduction at the cost of some spatial or temporal resolution, which may be acceptable in some cases. Other features such as “road mapping” helps to reduce fluoroscopy time

CONCLUSION AND RECOMMENDATIONS

The case studies above have shown that severe deterministic effects on patients, such as ulceration and skin necrosis, only have occurred under extreme working conditions, when the conditions is far from optimized. From the lessons learned, straightforward measures for preventing deterministic are derived. These measure are: a) placing the x-ray tube at a distance of 50 cm or more from the skin whenever possible, b) placing the image intensifier as close as possible to the patient, c) making selective use of high dose rate mode, by prior identification situations in which this use is really necessary, d) changing the projection where necessary and possible, and d) performing simple constancy checks to detect malfunctions in the automatic control systems.

Since some procedures may need to be repeated on the same patient, measures control doses and optimize protection are needed to ensure that doses in a single procedure are kept at the level of a fraction of the threshold dose for severe deterministic effects.

Optimization in interventional radiology is complex due to the complexity of procedures and the many technical factors that influence the dose. Training and quality assurance are indispensable in interventional radiology. Because of the complexity of equipment used in interventional radiology, quality control of the many parameters involved is time consuming and a careful selection of the parameters to be controlled in constancy checks and frequency is essential part of the programme. A strategy such as the one proposed in the DIMOND programme, is therefore needed.

REFERENCES

1. E Zeitler. Clinical aspects. In: Efficacy and radiation safety in interventional radiology. BfS-ISH-178/97 (Bundesamt fur Strahlenschutz), Salzgitter (Germany), 11-21, 1997.
2. RW Gunther, D Vorwerk, C Pfannenstiel. Interventionelle Radiologie. In: Henck FHW, Macheranch E (eds). Forschung mit Rontgenstrahlen, pp 237-256, Springer Verlag, Berlin, 1995.
3. W Huda, KR Peters. Radiation induced temporary epilation after a neuroradiologically guided embolization procedure. Radiology, 1994 193;642-644.
4. E Vañó, L Arranz, JM Sastre, C Moro, A Ledo, MT Garate, I Mínguez. Dosimetric and radiation protection considerations for some cases of patient skin injuries in interventional cardiology. British Journal of Radiology 1998:71;510-516.
5. Carstens GJ, Horowitz MB, Purdy PD, Pandya AG. Radiation dermatitis after spinal arteriovenous malformation embolization: case report. Neuroradiology 1996 May; 38 Suppl 1:S160-4.
6. Lichtenstein, D.A., Klapholz, L., Vardy, D.A., et al. Chronic radiodermatitis following cardiac catheterization. Archives of Dermatology 1996; 132: 663-667.
7. Shope TB. Radiation-induced Skin Injuries from Fluoroscopy. Radiographics 16: 1195-1199, 1996.
8. Sovik E, Klow NE, Hellesnes J, Lykke J. Radiation-induced skin injury after percutaneous transluminal coronary angioplasty. Case report. Acta Radiol 1996 May; 37(3 Pt 1): 305-6.
9. Nahass, G.T. Acute radiodermatitis after radiofrequency catheter ablation. Journal of the American Academy of Dermatology 1997; 36: 881-884.
10. Rosenthal LS, Beck TJ, Williams J, Mahesh M, Herman MG, Dinerman JL, Calkins H, Lawrence JH. Acute radiation dermatitis following radiofrequency catheter ablation of atrioventricular nodal reentrant tachycardia. Pacing Clin Electrophysiol 1997 Jul;20(7):1834-9.
11. Stone MS, Robson KJ, LeBoit PE. Subacute radiation dermatitis from fluoroscopy during coronary artery stenting: evidence for cytotoxic lymphocyte mediated apoptosis. J Am Acad Dermatol 1998; 38: 333-6.
12. Granel F, Barbaud A, Gillet-Terver MN, Reichert S, Weber M, Danchin N, Schmutz JL. Chronic radiodermatitis after interventional cardiac catheterization. Four cases. Ann Dermatol Venereol 1998 Jul;125(6-7):405-7.
13. Nahass, G. T. and Cornelius, L. Fluoroscopy-induced radiodermatitis after transjugular intrahepatic portosystemic shunt. American Journal of Gastroenterology 1998; 93: 1546-1549.
14. Stone MS, Robson KJ, LeBoit PE. Subacute radiation dermatitis from fluoroscopy during coronary artery stenting: evidence for cytotoxic lymphocyte mediated apoptosis. J Am Acad Dermatol 1998 Feb;38(2 Pt 2):333-6.
15 Dehen L, Vilmer C, Humiliere C, Corcos T, Pentousis D, Ollivaud L, Chatelain D, Dubertret L. Chronic radiodermatitis following cardiac catheterisation: a report of two cases and a brief review of the literature. Hearth 1998; 81:308-312.
16. Wagner L. Typical doses and biological implications. Categorical Course in Diagnostic Radiology Physics: Cardiac Catheterization Imaging. Editors: Nickoloff EL, Staruss KJ. 84th Scientific Assembly and Annual Meeting of the RSNA, 1998: 249-254.
17. T Shope, Food and Drug Administration, USA, Internet Site.
18. CL Lashbaugh, KF Hubner, SA Fry. The impact of human radiation tolerance upon radiation emergency management. In: The control of exposure to the public to ionizing radiation inthe event of accident or attack. Proceedings NCRP symposium. National Council on Radiation Protection. 1982;46-57.
19. A Widmark, J Hellesnes. Acute radiation injury after percutaneous transluminal coronary angioplasty (PTCA): A case report. In: Efficacy and radiation safety in interventional radiology. BfS-ISH-178/97 (Bundesant fur Strahlenschutz, Salzgitter) 1997;87-90.
20. E Vañó, L Arranz, JM Sastre, C Moro, A Ledo, MT Garate, I Mínguez. Dosimetric and radiation protection considerations for some cases of patient skin injuries in interventional cardiology. British Journal of Radiology 1998:71;510-516.
21. International Commission on Radiological Protection. Protection of the patient in diagnostic radiology. ICRP Publication 34 Annals of the ICRP 1982:9;2/3.
22. E Vañó, L González, F Benetez, F Moreno. Lens injuries induced by occupational exposure in non-optimised interventional laboratory. British Journal of Radiology 1998:71;728-733 (this reference seems to repeated in 94).
23. Th Schmidt, M Wucherer. Radiation Safety. In: Efficacy and radiation safety in interventional radiology. BfS-ISH-178/97. (Bundesant fur Strahlenschutz, Salzgitter, Germany, 1997, pp 23-33.
24. Faulkner, DA Broadhead, RM Harrison. Patient dosimetry measurement methods. Applied Radiations and Isotope. 1999.

25. Betsou S, Efstathopoulos EF, Katritsis D, Faulkner K, Panayiotakis G. Patient radiation doses during cardiac catheterization procedures. Br J Radiol 1998; 71:634-639.
26. Broadhead DA, Chapple CL, Faulkner K, Davies ML, McCallum H. The impact of cardiology on the collective effective dose in the North of England. Br J Radiol 1997; 70:492-7.
27. Vañó E, González L, Fernández JM, and Guibelalde E. Patient dose values in Interventional Radiology. Br J Radiol 1995; 68:1215-1220.
28. BJ McParland. A study of patient doses in interventional radiology procedures. British Journal of Radiology 1998:71;175-185.
29. E Vañó, Guibelalde, JM Fernández, L Gonzalez, JI Ten. Patient dosimetry in interventional radiology using slow films. British Journal of Radiology 1997:70;195-200.
30. Vañó, E.; González, L.; Guibelalde, E.; Fernández, J.M. and Ten, J.I. Radiation exposure of medical staff in Interventional and Cardiac Radiology. Br J Radiol 1998; 71: 954-960.
31. Hayashi N, Sakai T, Kitagawa M, Inagaki R, Yamamoto T, Fakushima T, Ishii Y. Radiation exposure to interventional radiologists during manual-injection digital subtraction angiography. Cardiovasc Intervent Radiol. 1998 May-Jun;21(3):240-3.
32. Zorzetto M, Bernardi G, Morocutti G, Fontanelli A. Radiation exposure to patients and operators during diagnostic catheterization and coronary angioplasty. Catheterization and Cardiovascular Diagnosis 1997; 40:348-351.
33. Steffenino G, Rossetti V, Dellavalle A, Garbarino M, Cerati R, Norbiato A, Uslenghi E. Staff dose reduction during coronary angiography using low framing speed. Br J Radiol 1996; 69: 860-864.
34. H Calkins, L Niklason, J Sousa, R El-Atassi, J Langberg, F Morady. Radiation exposure during radiofrequency catheter ablation of accessory atrioventricular connections. Circulation 1991:84;2376-2382.
35. DIMOND. European Concerted Action 1997-1999. Digital Imaging: measures for optimisation of radiological information content and dose.
36. Syllabus of a categorical course in Physics. Physical and technical aspects of angiography and interventional radiology. Radiological Society of North America (RSNA), 81th Scientific Assembly and Annual Meeting of the RSNA, 1995.