Film processing

Applying correct positioning, projections, exposure dates, etc., as described in the previous chapters is not enough to achieve a good end result of the radiographic examination. Correct and professional film processing is equally important.

The instructions in this chapter are valid both for automatic and manual film processing.

Automatic film processing

If an automatic film processing is used, it is important to follow the instructions that come with the machine. It should be noted, that even a small automatic film processor requires a separate, totally reliable electric supply for 3–4 kW, access to plenty of clean water, and well trained personnel for daily use and maintenance.

Manual film processing

Manual processing requires more precision and attention from the darkroom technician than does automatic film processing, especially if the room temperature is high and the ventilation is poor.

A detailed description of the activities in and around the darkroom is given. It is anticipated that for the processing, a strict time/temperature control will be used, i.e. without visual control of the development.

For a detailed description of the management and maintenance of the darkroom (and examination room), the reader is referred to the WHO manual "Quality Assurance Work", Geneva 2001 (WHO/DIL/01.3).
Procedures for manual film processing in a staffed darkroom

1. Bring the exposed cassette from the through-the-wall cassette hatch to the dry bench.
2. Unload the cassette.
3. Mark the film with the name of the examined person, date and name of the hospital. NOTE: film marking can be made outside the darkroom with a photographic marker if cassettes with a protected area at the back are used. This may shift the marking job from the darkroom attendant to the radiographer making the examinations, and will considerably improve the precision of the developing procedure.
4. Mount the film into a stainless steel frame of correct size.
5. Put the frame with film into the developing tank, and move it up and down twice, eliminating air bubbles on the film, ensuring that the whole film gets in contact with the developer.
6. Start the darkroom timer (which must be preset for the appropriate developing time for the actual temperature of the solution). Normal range is 5 → 3 minutes at 19 → 23 °C. With special precautions, the temperature range can be extended to 25 °C, using 2 minutes for the development. Shorter developing times than 2 minutes cannot be maintained properly in routine work.
7. Reload the cassette with a new film and return the cassette to the through-the-wall hatch.
8. After 1/2 minute in the developer, move the film frame up and down twice and make space for the next film frame to follow this one. Do not check the film blackening!
9. After the predetermined developing time (2–5 minutes depending on the temperature), transfer the film frame to the stop/intermediate wash bath (without checking the blackening!). Move it up and down two or three times during 1/2 minute, then transfer it to the fixing tank.
10. The fixing time is independent of the developing time, and is at least 3 minutes (for modern emulsions with low silver content), but preferably 5 minutes. Longer time will not damage the film. The film can be viewed in white light outside the darkroom after 3 minutes in the fixer, but should be returned to the fixer for another 3–4 minutes. Remember to put a lid on the developer tank before opening the darkroom door.
11. Transfer the film to the rinse tank, where it has to remain in running water for at least 30 minutes. Longer time will not damage the film. NOTE: the rinse water temperature should be close to the fixer temperature and not more than 27 °C.
12. Films are best dried (in their hangers) in a drying cabinet with forced ventilation, located outside the darkroom. If the air is heated, a thermostat must control the temperature so that it does not exceed 35 °C. If there is no drying cabinet, make sure that films hang where there is no dust and that the hangers are firmly fixed so they do not fall onto the ground. It is very difficult to remove dirt from a film, and scratches cannot be removed. If films in hangers are sent away from the darkroom, rinse them in the wash-tank for a few minutes when they are returned. Then dry them.
Technical background for the WHIS-RAD equipment

As stated in Chapter 1, the present manual is primarily adapted to the WHIS-RAD equipment (The World Health Imaging System for Radiology), but with appropriate modification the manual can be used with any type of adequate radiographic equipment.

In the present chapter, the technical requirements for the WHIS-RAD equipment, optimized for all general radiographic examinations, are given. Thus, equipments suitable for special procedures and fluoroscopy will not be mentioned.

General considerations

For the creation of an x-ray unit, designed to be successfully used for all general radiographic examinations, the demands on the construction optimizations and limitations together should produce excellent image quality with a low radiation dose. The most crucial points are the completely fixed imaging geometry from tube to cassette holder with fixed grid, and the choice of appropriate generator and tube in combination with appropriate film-screen combinations.

After many years of discussions and trials, a WHO expert group delivered the solution named WHIS-RAD, fulfilling the demands. The special “prone question mark” design of the stand (see figure 1) makes it possible to use it for all general radiographic examinations, and it is now successfully implemented in several thousands small and middle sized radiology departments around the world. (A detailed description and specifications of the WHIS-RAD are given in the WHO publication “Consumer Guide for the purchase of X-ray equipment”, Geneva 2000, WHO/DIL/00.1 Rev.1).

The three most important influences on the design, to be discussed below, are:

1. Requirements related to the objects to be radiographed.
2. Imaging conditions affecting radiographic image quality.
3. The choice of a suitable x-ray source.

Figure 1 (from WHO/RAD/TS/95.1): The main features of the WHIS-RAD stand.
Radiographic objects

Three extreme imaging situations for which the equipment must be suitable:

The very thin object represented by the hand requires low tube tension in the range of 45–60 kV resulting in high contrast, small geometric magnification giving negligible geometric unsharpness, and an image recording medium with excellent detail resolution.

The very dense object, represented by the lateral view of the lumbarspinal junction, may have a density corresponding to as much as 30 cm of water. The choice of kV-values becomes a compromise between required film density and acceptable image contrast. In practice the tube tension should not be more than 90 kV with less than 4% ripple.

A long focus-film distance or a very small focal spot is needed; an FFD of 120 cm or more in combination with a focal spot of 1 mm or less is acceptable. The screen-film combination will be a compromise between recording system speed (sensitivity) and detail resolution.

The chest represents a unique imaging situation. High tube tension (kV) and very short exposure times should be used. In order to suppress the skeletal image, penetrate through the heart, and emphasize the contrast between air and soft tissue, the tube tension must be in the range of 110–140 kV with less than 4% ripple.

The image quality is improved if the radiation detector has low sensitivity in the lower end of the radiation spectrum. The high-kV technique is necessary to get suitable radiographic contrast and sufficiently short exposure times. The exposure times must be shorter than 50 ms.

The requirement for detail resolution is not very high in chest radiography. Most high speed screen-film combinations with a nominal speed larger than 250 cannot be used with standard focus-film distances of 150–180 cm, unless the X-ray generator can handle mAs-values down to 1 mAs with proper 26% increments between steps.

Image contrast

Image contrast is influenced by tube tension (kV) and the ratio between primary image-producing radiation and scattered radiation.

The image contrast is primarily chosen by selection of a suitable kV-value. For bone the kV should be as low as possible.

In chest radiography the most suitable image contrast is produced between 110–140 kV (ripple <4%).

Image contrast is strongly influenced by scattered radiation. If less than 1 liter of body tissue is irradiated, the scatter can be ignored. When the tube tension is below 60 kV and less than 2 liters of body tissue are irradiated, e.g. a knee imaged on an 18 x 24 cm film, no action has to be taken against scattered radiation. In all other radiographic situations action must be taken to reduce the amount of scatter reaching the film; best done by interposition of a grid between object and cassette.

The choice of a grid is a very complex problem. A grid with the ratio 10:1 usually is the best choice for general radiography.

Modern grids with 40 lines/cm or more may remain stationary without disturbing the image, if the required image detail resolution is no more than 4 linepairs/mm.

Detail resolution

Detail resolution is affected by geometric unsharpness, motion unsharpness and unsharpness originating in the image recording medium, (usually a screen-film combination). All these factors are interrelated.

Geometric unsharpness is not easily defined in simple terms. A geometric unsharpness of 0.25 mm should not be exceeded. This corresponds to approximately 4 lp/mm.

In practice the magnification seldom exceeds 1.25 but may occasionally reach 1.35 times. X-ray tubes with a nominal focus size in the range of 0.8–1.0 mm are satisfactory in general radiography. The loadability should be 25–30 kW for 0.1 s and 30 kW’s within 1–2 s.

Motion unsharpness is a type of geometric unsharpness which is directly proportional to the velocity of the moving object. The following exposure times should not be exceeded:

Imaging conditions

The radiographic image quality is influenced by image contrast, detail resolution and the physical shape of the radiographic stand.
In the immediate vicinity of the heart 10 ms
In the chest in general (PA chest) 50 ms
For bone 1–2 s

Image recording medium. General purpose radiography is manageable using screen-film combinations with only two different speeds. For all radiographic images produced behind an antiscatter grid a resolution of 4 lp/mm is satisfactory. For images produced without a grid and with cassette size not exceeding 18x24 cm, the resolution should be at least 6 lp/mm.

Calcium-tungstate screens for blue sensitive film. Details screens with a relative speed of 50 and a resolution of 8 lp/mm or more may be used for radiography of the extremities.

Fast or HiPlus screens have a relative speed of 200 and resolve about 3.5–4 lp/mm. They are used for all other examinations, including chest.

Modern green emitting intensifying screens for green-sensitive film are available in four different speed groups (nominal speed at 80 kV). (At 40 kV the speed values are halved.)

<table>
<thead>
<tr>
<th>Speed</th>
<th>Speed</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine</td>
<td>100</td>
<td>8–10 lp/mm</td>
</tr>
<tr>
<td>Medium</td>
<td>200</td>
<td>6–8 lp/mm</td>
</tr>
<tr>
<td>Regular</td>
<td>400</td>
<td>4–6 lp/mm</td>
</tr>
<tr>
<td>Fast</td>
<td>800</td>
<td>about 4 lp/mm</td>
</tr>
</tbody>
</table>

The manual recommends the use of Fine screens for extremities, Medium screens for chest, and Regular screens for everything else.

Physical shape of stands for general radiography
It should be possible to X-ray a standing adult patient from shoulders to knee-joints. This requires that the horizontal x-ray beam can be used at a distance from the floor of 50–170 cm. Examinations of cervical spine and paranasal sinuses can be made with the patient standing or sitting. Note, however, that a proper skull examination should be done with the patient lying down. It must also be possible to x-ray a recumbent patient with a horizontal beam from head to feet.

It must be possible to x-ray a lying patient on a radiolucent movable table-top with vertical x-ray beam and with a beam angulated up to ±30° from the vertical direction. This must be achieved with no more than 1.3 x magnification of the structure of major interest.

It must be possible to examine the arm of a sitting patient with vertical x-ray beam, when the arm is at right angles at the shoulder and the elbow. This requires a horizontal cassette position 100–110 cm from the floor (e.g. on the top of the horizontal WHIS-RAD cassette holder). All these patient positions are often achieved by the use of two different examination stands. It is possible, however, to design a single stand to do them all. Such stands are the WHO-BRS/1985 Unit and the later developed WHIS-RAD Unit. These WHO specified units have a curved swivel arm with an FFD of 140 cm and fixed imaging geometry, but still the possibilities to angulate the x-ray beam ±30° from the vertical and the horizontal direction without excessive magnification. The gap between patient and film is only 25 mm in chest radiography, which at heart volume measurements is equivalent to 38 mm at an FFD of 150 cm or 65 mm at an FFD of 180 cm.

Fixed geometry guarantees:
1. Correct centering of the x-ray beam to the film,
2. Permanent centering of the grid, resulting in lowest possible visibility of the grid lines,
3. No variation in exposure requirements due to change in FFD. The long FFD allows tilted views in spite of the fixed geometry.

Angulation of the x-ray beam and variable film-focus distance in relation to the grid always results in longer exposure times and reduced image quality. A variable film-focus distance is also a common reason for erratic exposure!

X-ray source
The demands on the x-ray source can be concluded from what has been said about the dimensions of radiographic objects and about imaging conditions.

High-tension generator: Single-phase 50/60 Hz x-ray generators or capacitor discharge generators with the capacitor in the high-tension circuit, cannot properly handle the extreme exposure requirements, represented by the chest and lateral lumbar-sacral junction. Only 3-phase x-ray generators with electronic switching in the high-tension circuit and multipulse x-ray generators, using high-
frequency inverter technology, are capable of delivering the exposure factors required. Three-phase 50/60 Hz x-ray generators are disappearing from the market and are replaced by cheaper and more reliable multipulse generators.

Multipulse x-ray generators, using capacitors or batteries for energy storage, are now available to connect to weak or unreliable power lines or small petrol-driven AC generators.

X-ray tubes, used with the WHIS-RAD, must handle at least 25 kW for 0.1 s (= nominal rating) and half that for 1.6 s (= 20 kWs). The focus diameter must not exceed 1.0 mm (nominal value). Tubes which fulfill these requirements are available with focal spots in the range of 0.6–1.0 mm. If the long FFD of 140 cm is used for all examinations, the anode angle may be as small as 10°–13°. If the FFD is 100 cm, the anode angle should be 13°–15°.

Values of x-ray tube voltage. For didactic reasons the choice of kV-values is limited to a small number of fixed steps. In practice this leaves a satisfactory choice of radiation qualities for clinical radiography.

Recommended x-ray tube voltages

<table>
<thead>
<tr>
<th>kV</th>
<th>46</th>
<th>53</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue steps</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Green steps</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Exposure changes (steps with 26% increments) between kV values available with the WHIS-RAD unit with blue and green emitting screen film system

Values of current-time product shall be indicated in mAs, chosen as decimal multiples and sub-multiples from Renard Series 10 (ISO Standard 497/1973):

R’10, the Renard Series 10

<table>
<thead>
<tr>
<th>mAs</th>
<th>1</th>
<th>1.25</th>
<th>1.6</th>
<th>2</th>
<th>2.5</th>
<th>3.2</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
</table>

The range of fixed mAs values to be used in the WHIS-RAD

<table>
<thead>
<tr>
<th>mAs</th>
<th>0.5</th>
<th>0.63</th>
<th>0.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.25</td>
<td>1.6</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>12.5</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td>100</td>
<td>125</td>
<td>160</td>
<td>200</td>
</tr>
<tr>
<td>250</td>
<td>320</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NOTE: It is not required that the entire range of mAs-values is available at all kV-values. Thus, it is acceptable that only 12 kWs is reached at 120 kV.

Comment: When the R’10 series is used, each exposure step has exactly the same size in the entire range (+26%). Film blackening should always be altered by mAs-variations, and never by kV-variations. Tube voltage (kV) variations are used to influence the image contrast.