Balancing image quality and dose in diagnostic radiology

Abstract The formation of images in diagnostic radiology involves a complex interplay of many factors and the ideal balance is to obtain an image, which is adequate for the clinical purpose with the minimum radiation dose. Some factors are classified as physical parameters and can be measured objectively in physical test phantoms, but the diagnostic images must still be interpreted by human observers which does not always mean an ideal observer. This subjective nature of image interpretation makes the objective approach to a full assessment difficult. The ideal method for evaluation of imaging techniques is through clinical trials. Scoring of image quality criteria relating to features observed in a normal clinical radiograph gives a simple method through which image quality can be assessed and related to the radiation dose used. But if optimal performance is to be achieved, it is necessary to understand both the influence of the physical factors in the image formation on dose and image quality and to apply the correct methodology in these analyses of optimisation of the imaging process.

Keywords Image quality · Radiation dose · Quality criteria · Optimisation

Definition of image quality

An image of the human body in diagnostic radiology is a representation of structures of organs and tissues under investigation and a general definition of image quality must address the effectiveness with which the image can be used for its intended task. The complexity of the diagnostic task and the physical construction of the imaging system impose limitations on the fundamental quality of the detected image data. Also the ability of the human observer to utilize a displayed version of the image data can often be the limiting factor affecting the diagnostic result and therefore it cannot always be assumed that the quality of the displayed image reflects the quality of the data acquired by the imaging device. On this background the imaging process is normally divided into two stages: data is first captured from the field of radiation; the detected image is then processed and displayed. In modern digital radiology this is a quite natural way of considering the imaging process. Image quality is to a large extent a descriptor of the subjective interpretation of visual data and as such cannot have a simple analytical definition. Before a realistic assessment of clinical image quality can be made, the requirements need to be defined. The ideal set of parameters describing image quality should give a measure of the effectiveness with which an image can be used for its intended purpose. They should convey sufficient information to the clinician to allow a medical decision to be made with an acceptable degree of certainty.

Definition of dose

The International Commission on Radiation Units and Measurements (ICRU) [1] has defined absorbed dose, D, in Gy as the amount of energy deposited in a medium per unit mass and various dosimetric quantities are used for...
patient dosimetry. Two categories of doses to patients in diagnostic radiology are of most importance, the effective dose, \( E \), in \( \text{mSv} \) \([2]\), which takes account of dose equivalents to radiosensitive organs and the other category is skin dose or entrance surface dose. Effective dose is calculated using the equation:

\[
E = \sum_T w_T H_T = \sum_T w_T \sum_R w_R \cdot D_{T,R} \tag{1}
\]

Effective dose is the sum of weighted equivalent doses (HT) in irradiated tissues multiplied by a weighting factor \( w_T \) for that tissue and \( w_R \) is the radiation weighting factor, which is equal to one for diagnostic radiation qualities. Tissue weighting factors are given in Table 1. Most interest is concerned with effective dose since this relates to the risk of stochastic effects such as cancer induction. Evaluations of effective dose involve calculations which are, however, not trivial (Table 1). Statistical computational methods based on Monte Carlo techniques are applied to the simulation of the passage of large numbers of single X-ray photons through the body of a patient. The energy deposition within the body from the photon interactions is used to derive conversion factors for different anatomical projections making up the actual examination \([3]\). Simple entrance skin dose measurements can instead be used as an indicator of effective dose for particular radiographic projections. Skin dose measurements also give an indication of the greatest dose from an exposure and the skin is therefore a risk organ for deterministic effects and skin injuries resulting from fluoroscopically guided interventional procedures have been reported \([4]\). Methods for measuring radiation doses have been described in detail elsewhere \([5]\).

### Parameters affecting patient dose and image quality

Several factors are involved where a balance between patient dose and image quality are attempted.

#### Radiation quality

Radiation quality refers to the distribution of photon energies in the X-ray beam. The contrast between different components in an image depends on the mechanisms through which photons interact with tissue and these vary with photon energy, as does the probability that a photon will be absorbed and so contribute to the radiation dose. Two interaction mechanisms are important at diagnostic X-ray energies, the photoelectric effect and the Compton scattering. The photoelectric effect absorbs all the energy from the incident photon involved in the interaction and the probability of interaction varies with atomic number as \( Z^4 \) per atom; thus, photoelectric interactions give reasonable contrast between different structures in tissue for not to high-photon energies. On the other hand, contrast provided by Compton scattering is much lower, because it is derived solely from differences in the electron density of the tissue, and any of the resulting photons scattered on the electrons which reach the image receptor contribute to image noise. The Compton scattering is independent of the atomic number; thus, images produced by X-ray beams from which there is a high proportion of photoelectric interactions will give better image contrast and have less background noise.

In practice, X-ray beams contain photons with a wide range of energies—a spectrum. The interaction cross section for the photoelectric effect decreases rapidly with photon energy (as \( -E^{-3} \)), whereas that for Compton scattering is comparatively independent of energy in the diagnostic energy range. The same two processes determine the numbers of photons, which pass through the body and contribute to the final image; thus “softer” X-ray beams which contain more lower-energy photons give better image contrast, but a greater proportion of the photons are absorbed in the body, so it is necessary to use a larger radiation intensity and give a higher radiation dose to the patient. The X-ray beam quality chosen for a particular radiological examination must achieve a balance between these factors as well as taking account of variations in the sensitivity of the imaging system with photon energy.

Differences in the quality of the X-ray beam change the effective dose in a different manner from the entrance surface dose. Softer X-ray beams will give a proportionately higher radiation dose to the skin surface, but the ratio of effective dose to entrance surface dose will be lower; therefore, it is important to take account of both how the entrance surface dose will vary when considering changes which affect beam quality, where tube potential and beam filtration are the most important factors.

#### Tube potential

Tube potential determines the proportion of high-energy photons in an X-ray beam. It can be selected for each examination. The optimum choice depends on the part of the body being imaged, the size of the patient and the

<table>
<thead>
<tr>
<th>Tissue weighting factor ( (w_T) )</th>
<th>Tissue or organ</th>
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<tbody>
<tr>
<td>0.20</td>
<td>Gonads</td>
</tr>
<tr>
<td>0.12</td>
<td>Bone marrow (red), colon, lung, stomach</td>
</tr>
<tr>
<td>0.05</td>
<td>Bladder, breast, liver, oesophagus, thyroid</td>
</tr>
<tr>
<td>0.01</td>
<td>Skin, bone surface</td>
</tr>
<tr>
<td>0.05</td>
<td>Remainder</td>
</tr>
</tbody>
</table>