Patient-based radiographic exposure factor selection: a systematic review

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Keywords
Exposure, radiography

Abstract

Introduction: Digital technology has wider exposure latitude and post-processing algorithms which can mask the evidence of underexposure and overexposure. Underexposure produces noisy, grainy images which can impede diagnosis and overexposure results in a greater radiation dose to the patient. These exposure errors can result from inaccurate adjustment of exposure factors in response to changes in patient thickness. This study aims to identify all published radiographic exposure adaptation systems which have been, or are being, used in general radiography and discuss their applicability to digital systems.

Methods: Studies in EMBASE, MEDLINE, CINAHL and SCOPUS were systematically reviewed. Some of the search terms used were exposure adaptation, exposure selection, exposure technique, 25% rule, 15% rule, DuPontTM Bit System and radiography. A manual journal-specific search was also conducted in The Radiographer and Radiologic Technology. Studies were included if they demonstrated a system of altering exposure factors to compensate for variations in patients for general radiography. Studies were excluded if they focused on finding optimal exposures for an ‘average’ patient or focused on the relationship between exposure factors and dose.

Results: The database search uncovered 11 articles and the journal-specific search uncovered 13 articles discussing systems of exposure adaptation. They can be categorised as simple one-step guidelines, comprehensive charts and computer programs.

Conclusion: Only two papers assessed the efficacy of exposure adjustment systems. No literature compares the efficacy of exposure adaptations system for film/screen radiography with digital radiography technology nor is there literature on a digital specific exposure adaptation system.

Optimal exposure is necessary for accurate diagnosis as well as adherence to the ALARA principle. Underexposed images result in increased quantum mottle, reduced image quality of the radiograph and may impede diagnosis. Overexposure reduces quantum mottle, improving image quality, and is less likely to be rejected by radiologists; thus there is a trend towards this technique. However, a higher exposure means an increase in dose to the patient. This trend to overexposure is known as dose creep and is a growing concern with digital radiography. DDR, if used optimally, can provide equivalent image quality at a lower dose. Both CR and DDR can reduce the dose as the wider exposure latitude and post-processing algorithms minimise the need for repeats due
to exposure selection errors. Compagnone et al. compared film/screen technology, CR and DDR, and found that CR needs a higher exposure to the patient to provide equivalent image quality to film/screen. However, the direct digital system was able to produce equivalent image quality to film/screen at lower dose, reduced by 13–66%. A well-defined system of exposure adaptation is required to allow accurate exposure selection for a variety of patients. Some research has gone into finding optimal exposure parameter settings for the ‘average patient’. However, the patients that radiographers encounter will deviate from the ‘average’ and exposures will need to be adjusted accordingly. The aim of the following review is to identify all published radiographic exposure adaptation systems which have been, or are being, used in general radiography and discuss their applicability to digital systems.

Methods

A search of Medline, Embase, CINAHL and Scopus databases was performed using the intervention terms combined with cohort terms, which are listed in Table 1. A wide range of intervention terms was used as there is no standard term for ‘exposure adaption system’ and the terminology for exposure parameters has changed over time. A variety of radiography-related terms were considered to ensure a complete search of the literature. The entire time period available was reviewed which ranged from 1949 to present. The search resulted in 3066 articles which were filtered down to 11 that satisfied the inclusion exclusion criteria. The search pathway is presented in Figure 1.

Studies that were included in this review were those that demonstrated a system of adjustment of multiple exposure factors which could be used in radiographic practice and those that were related to human general radiography, both film/screen and digital technology.

Studies that were excluded examined the optimum exposure factors for an examination of an average patient and those that focused on the relationship between exposure factors and dose.

Only 11 articles from the database search were accepted into this review. Another 13 articles were found through a journal specific search of the Radiologic Technology from 1961 to 2000 and The Radiographer from 1948 to 2000. These journals were selected as they were considered to be the most likely locations to find the articles related to exposure technique. All the literature found is summarised in Table 2. This study required no participants, thus no ethical approval was required.

Table 1. List of search terms used in database search.

| Intervention (all terms combined with ‘OR’) | Cohort               |
|-------------------------------------------|----------------------|
| Exposure determination                    | Radiography          |
| Exposure adaptation                       | Radiographer         |
| Exposure modification                      | Technician           |
| Exposure parameter                        | Radiologist          |
| Exposure factor                           | Radiologic technician|
| Exposure selection                        | Radiologist technician|
| Exposure adjustment                       | Variable kvp         |
| Exposure decision                         | Variable kilovoltage |
| Exposure alteration                        | Variable kv          |
| Exposure correction                        | Variable peak kilovoltage |
| Exposure variation                        | System of exposure adaption |
| Exposure technique                        | Bit system           |
| Exposimetry                               | Siemens point system |
| Exposure calculation                      | 25% rule              |
| Exposure setting                          | 15% rule              |
| Exposure approach                         | Exposure chart        |
| Technique chart                            |                      |

Results

Patients that visit the radiology department naturally vary in thickness, tissue composition and pathology. The radiographic exposure parameters that are set for an examination should be selected with consideration of these variations. In order to clarify how this is achieved, several methods have been published over the years. Exposure adjustment systems can be categorised into simple techniques, which minimises the exposure adaptation steps, mathematical approaches, comprehensive charts and technological approaches which eliminate mental calculations and chart searching through the use of technology.

Simple techniques

The early approaches to exposure adjustment were designed to simplify the process for radiographers by keeping all factors constant but one. The ‘optimal kVp technique’, as described by Lyons, involves selecting a kVp which provides the best contrast for the anatomy being imaged and adjusting the mAs based on patient thickness; where it is doubled when the patient was deemed to be above average in thickness and halved when below. This makes selecting exposure relatively simple but the division of patients into three categories is arbitrary and is vulnerable to subjectivity.

An opposing technique is the ‘variable kVp technique’ which involves keeping all parameters constant except the
kVp. This technique adjusts exposure factors for variations in patient thickness, where the kVp is increased by two for each centimetre increase in patient thickness. However, the variation in kVp for different patient thicknesses will lead to a variation in the contrast of radiographs of the same anatomy.

The pegged kilovoltage technique was developed as an improvement to the optimal kilovoltage technique. The pegged kilovoltage technique follows the same principle as the optimal kilovoltage technique, however there are specific kVp values that must be used (Table 2). The mAs is adjusted based on a half value layer (HVL) of 3 cm, where a change in thickness of 3 cm requires the mAs to be doubled or halved. This allows adaptation of exposure without a change in image contrast. This approach to mAs adjustment is more precise than the optimal exposure technique. Furthermore, a step in kVp corresponds to a 50% change in exposure (Table 2). This guideline allows the kVp to be adjusted instead of mAs when the mAs calculated goes beyond the tube limits or when a change in image contrast is required.

Mathematical approaches

Mathematical approaches allow for the adjustment of factor(s) per centimetre making exposure selection more precise. The HVL refers to the thickness of a material required to produce an exit beam that is half the intensity of the primary beam. In the literature there is a discrepancy between the HVL of human tissue. In some papers, the HVL is 4 cm, while others state that it is 3 cm. McDaniel’s water bath study found that the
Table 2. The literature reviewed and a summary of the exposure adaptation systems described.

| Author/Paper | System                          | Study Design                                                                 | Description                                                                                                                                                                                                                                                                                                                                 | Limitations                                                                 |
|--------------|--------------------------------|-----------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|
| Simon¹³      | 1. ‘Disc system’                | Description of the system(s)                                               | 1. A system composed of concentric discs used to adjust exposure. Disc 1: Line up the parameters for an optimal exposure: tube current (mA), exposure time (s), tube potential (kVp), weight (lb). Turn the weight wheel to the desired weight and a set of optimal exposure parameters will be provided. If a certain kVp, mA or time is desired, turning the corresponding wheel will lead to compensation through adjustment of another factor. Disc 2: Same control as disc 1. The factors addressed are tube unit, grid, film/screen and tissue thickness combined into a density correction (DC) factor, SID (inches), kVp, mA and time. The mA and time adjustment based on linear logarithmic relationship with thickness. The kV scale based on the Bierman and Boldingh formula: \((kV)^{5/9} \times mAs = \text{constant.}\) | 1. None stated in article.                                                                 |
|              |                                |                                                                             | 2. Finding kilovoltage peak (kVp)                                                                                                                                                                                                                                                                                                             | 2. None stated in article.                                                  |
| Gyss¹⁴       | 1. Optimum kilovoltage technique| Description of the system(s)                                               | 1. All factors including kVp are fixed except time. Optimum time is found for an average patient. For a thicker than average patient, the time is doubled and for a thinner than average patient it is halved.                                                                                                                                          | None stated in article.                                                     |
|              |                                |                                                                             | 2. Variable kilovoltage technique                                                                                                                                                                                                                                                                                                           | 2. ‘Radiographs of any given part will vary in contrast.’ (p. 76)           |
|              |                                |                                                                             | 2. The kVp is adjusted ‘to compensate … for part thickness … [and] radiopacity of the part.’ (p. 76) To adjust exposure for extremities that are imaged with a screen the kVp is adjusted 2 kVp per cm and without screen kVp is adjusted 3 kVp per cm. To adjust exposure because of radiopacity the patients are divided into three categories; hard to penetrate, normal and easy to penetrate. Hard to penetrate needs the addition of 4 kVp to | (Continued)                                                                 |
| Author/Paper | System | Study Design | Description | Limitations |
|--------------|--------|--------------|--------------|-------------|
| Power\textsuperscript{15} | 1. Half value layer (HVL) | Description of the system(s) | 1. An `increase in thickness of body tissue of 3 cm. requires DOUBLE the exposure to achieve the same amount of film blackening`\textsuperscript{16} (p. 16) [sic] | 1. None stated in article. |
|               | 2. 25% rule | Description of the system(s) | 2. Every cm increase of patient thickness requires a 25% increase in milliampere-seconds (mAs). | 2. None stated in article. |
| Lyons\textsuperscript{16} | Optimum kilovoltage technique | Description of the system(s) | All factors including kVp are fixed except time. Optimum time is found for an average patient. For a thicker than average patient the time is doubled and for a thinner than average patient it is halved. | None stated in article. |
| Pinson\textsuperscript{17} | Unit step radiography | Description of the system(s) | Involves the use of a calliper which has been modified to have a scale of `units` opposite to a centimetre scale. The values of the exposure parameters are also assigned `units`. Measure the anatomy to be imaged with this calliper and the `units` is read. The correct exposure is when the sum of the `units` of the set of exposure parameters matches the `units` read off the calliper. | ‘The greatest error will occur when the calliper measurement is midway between a whole number and the next half unit’. (p. 9) |
| McDaniel\textsuperscript{18} | HVL | Water Bath Study Radiographs made each time there was an increase in 4 cm of water. Then for every 3.5 cm increase. Consistency of image density was observed when the exposure (time) was double in response to each increase. | For every 4 cm increase in patient thickness requires a doubling of exposure (time) in order to achieve an image of equal density. The study found slight density fluctuations when doubling exposure for every 4 cm increase in thickness and found more consistent density occurs when doubling exposure for every 3.5 cm increase in thickness. | The more accurate value for HVL is between 3.3 cm and 3.8 cm but the use of 4 cm has a negligible effect and is suitable for practical use. |
| Funke\textsuperscript{19} | 1. Pegged kilovoltage technique | Description of the system(s) | 1. The kVps 44, 51, 57, 65, 75, 86, 100 and 120 are the only ones required for most radiologic examinations. Each step in this sequence delivers twice the exposure to the film than the preceding step. For each part of anatomy, set of one these values as optimum and only adjust mAs in response to an increase in patient thickness. | 1. Beyond certain limits it becomes impractical to increase the milliampere-seconds further because the limits of safe tube loading or acceptable exposure times cannot be exceeded. Thus, a change in kVp is required which alters the contrast of the image. |

(Continued)
Table 2. Continued.

| Author/Paper | System | Study Design | Description | Limitations |
|--------------|--------|--------------|--------------|-------------|
| 2. HVL       |        |              | 2. ‘The milliampere seconds should be doubled (or reduced by one half) for every three centimetres of tissue thickness’. (p. 207) [sic] | 2. This method fails when the anatomy thickness is greater than 30 cm, particular with high kVp and a HVL of 4 cm should be used. |
| Power²⁰      | 1. ‘Rule of the thumb’ | Narrative review | 1. Time needs to be halved in order to achieve an image of equivalent density when the kVp is increased by 10 kVp. | 1. Only suitable for a kVp between 60 and 80 kVp. If the kVp is outside this range there is an error of 3–5 kVp. |
|              | 2. Siemen's point system | | 2. Each region of anatomy is assigned points. The exposure parameters are also assigned points. If the sum of the points of the selected parameters matched the points of the anatomy being imaged then the exposure should be correct. | 2. It fails at the extreme ends of the kVp range (40 and 117 kVp). |
|              | 3. Unit step radiography | | 3. Exposure parameters and patient thicknesses were assigned ‘units’ and an increase in one ‘unit’ equals a doubling of exposure. | 3. It fails at the extreme ends of the kVp range (40 and 117 kVp). |
|              | 4. Variable kVp technique | | 4. The mAs is kept constant and the kVp is adjusted. An increase of 2 kVp is required for each centimetre increase in patient thickness. | 4. This technique causes a variation in contrast between different patient thicknesses |
|              | 5. Optimum kVp technique | | 5. The kVp is ‘fixed at an optimum level of contrast’. (p. 11) The mAs value varies and is selected based on patient thickness. | 5. None stated in article. |
|              | 6. 25% rule | | 6. Every cm increase of patient thickness requires a 25% increase in mAs. | 6. None stated in article. |
| Eastman²¹    | Body habitus factor | Description of the system(s) | The body habitus factor is found by dividing the patient’s weight by their height. This value is then located on the chart provided in the article to find the appropriate exposure parameters. | None stated in article. |
| Eastman²²    | Bit system of technic conversion | Description of the system(s) | “‘Bits’ are assigned to the factors controlling exposure such as kilovoltage and milliampere-seconds’. (p. 75) ‘As long as the Bit totals remain constant, film density remains approximately constant’. (p. 76) | None stated in article. |
| Kratzer²³    | Supertech | Description of the system(s) | A system comprised of 3 charts. Chart A has a list of projections and a slider behind it. The slider is moved in order to display the measured thickness in the box next to the projection. Chart B provides correction factors for a | The paper is not clear on how these three charts work to provide an adjusted exposure factor. |

(Continued)
| Author/Paper | System | Study Design | Description | Limitations |
|--------------|--------|--------------|--------------|-------------|
| Atkins²⁴     | 1. Bit system of technic conversion | Narrative review | 1. 'Increasing one whole number in the Bit System, doubles the exposure, with a corresponding increase in density'. (p. 389) | 1. None stated in article. |
|              | 2. The thumb rule | | 2. 'As you double milliampere seconds, you reduce kilovoltage by 10 kilovolts’. (p. 389) | 2. This only applies when the kVp is decreased from 80 kVp to 70 kVp |
|              | 3. Variable kilovoltage technique | | 3. 'Milliampere seconds . . . are kept constant and kilovoltage is varied by 2 kVp per centimeter of thickness’. (p. 389) | 3. A change in kVp also leads to a change in contrast. |
|              | 4. Optimum kilovoltage technique | | 4. 'When milliampere seconds and adequate kilovoltage values are established for the average patient, one half the milliampere-seconds value is then used for the small patient, and twice the milliampere-seconds value is used for the large patient’. (p. 389–390) | 4. None stated in article. |
|              | 5. Automatic exposure control (AEC) | | 5. This technique involves employing a ‘fixed voltage and fixed milliampere, with the time of exposure determined by the sensing device’. (p. 390) | 5. Incorrect centring leads to an incorrect exposure. |
| Stopford²⁵   | Log₁₀ technique chart | Description of the system(s) | Log₁₀ factor is the value needed to increase the parameter per cm. Log₁₀ factor = \[\log_{10}(\text{mAs for large}) - \log_{10}(\text{mAs for small})/\text{(cm. difference)}\] Allows you to develop charts with mAs provided for each cm. The same can be done for kVp. | None stated in article. |
| Markivee et al.²⁶ | 1. AEC | Description of the system(s) | 1. 'Terminates the X-ray beam when a preset level has been accumulated’. (p. 113) | 1. Errors in exposure occur when • the detector is not correctly positioned over the “critical” part of the body’ (p. 113) • it is correctly positioned but the critical part is unusually radiolucent or radiodense’ (p. 113) • it is correctly positioned but the remainder of the anatomy to be X-rayed is unusually radiolucent or radiodense’ (p. 113) • A film/screen combination is different to |
| Author/Paper | System          | Study Design                              | Description                                                                                     | Limitations                                                                 |
|-------------|-----------------|-------------------------------------------|-------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------|
| Horsington? | 2. Unit step    | 2. An exposure value scale (XVS) number is assigned to the centimetre thicknesses of body part and can be altered to suit the tissue composition. XVS numbers are also assigned to the values of the exposure parameters; kilovoltage, milliamperage and time. An accurate exposure comes from the selection of parameters whose XVS total matches the XVS of the anatomy to be imaged. Exposure parameters can also compensate for changes in ‘film speed, screen speed, target-to-film distance . . ., single phase or three phase power supplies, half wave or full wave rectification and the numerous patient variables’. (p. 114) | None stated in article. |
|            | radiography     | 3. Based on a modified version of unit step radiography to match the modern day techniques. It requires the input of ‘patient, equipment and other physical factors’ (p. 114) which leads to a total XVS number which in turn leads to a set of exposure parameters being displayed. Three sets are displayed which vary in kVp by 1 XVS number but all will produce the same density image. It is possible to adjust technique to different electrical powers and different amounts of filtration. | 3. Errors occur when the patient isn’t properly measured. Using the system increases the time required per examination. Wide coverage of factors that influence exposure increase amount of input data required and thus increases length of each examination. | None stated in article. |
|            | 3. Computer     | 3. Errors occur when the patient isn’t properly measured. Using the system increases the time required per examination. Wide coverage of factors that influence exposure increase amount of input data required and thus increases length of each examination. | None stated in article. |
|            | program         | Description of the system(s)              |                                                                                                 |                                                                              |
| Author/Paper | System | Study Design | Description | Limitations |
|--------------|--------|--------------|-------------|-------------|
| Enright²⁸     | Linear logarithmic relationship between mAs and patient thickness | Phantom Study | Measure mAs need for varying patient thickness at each constant kVp. 60–120 kVp was tested at 5 kVp increments. Grid ratio used was not indicated. SID set at 100 cm | This technique doesn’t account for tissue composition. |
| Lewis²⁹      | Computer program | Description of the system(s) | It requires the input of a variety of factors to allow the calculation of an appropriate set of exposure parameters that is displayed. The factors requested are body part, projection, intensifying screen, initial exposure factors and the exposure factor to be adjusted. | None stated in article. |
| Kelly³⁰      | 1. Half value layer (HVL) | Description of the system(s) | 1. ‘An increase in tissue thickness of 3 cm would require that the “Base” exposure be doubled to maintain the required film density’. (p. 19) |
|              | 2. 25% rule | | 2. Every cm increase of patient thickness requires a 25% increase in mAs. |
|              | 3. 15% rule | | 3. A 15% increase in kVp requires a 50% decrease in mAs in order to achieve the same exposure. |
| Sterling³¹   | AEC | Description of the system(s) | The AEC ‘terminates the exposure when the proper level of radiation has been reached’. (p. 422) This allows the X-ray system to provide ‘consistent radiographic densities’. (p. .426) | Incorrect positioning and/or chamber selection and/or bucky selection will lead to incorrect exposure. The desired exposure time needs to be greater than the minimum response time. The backup timer needs to be the maximum exposure required in case of malfunction. The ‘AECs must be calibrated for the film screen combination in use’ (p. 425) and ‘to provide the required image density with the film screen combination in use’. (p. 426) |

(Continued)
## Table 2. Continued.

| Author/Paper | System | Study Design | Description | Limitations |
|--------------|--------|--------------|-------------|-------------|
| Artz³        | AEC    | Description of the system(s) | A radiation detection device is place in front of or behind the image receptor and measures the residual X-ray beam. When sufficient X-rays have reached the detector the beam is stopped. | None stated in article. |
| Al-Balool and Newman³² | 1. 25% rule | Water bath used to simulate a patient. 50–150 kVp at 10 kVp increments was tested. | 1. Every cm increase of patient thickness requires a 25% increase in mAs. | 1. The 25% rule only works well for most radiographic situations (low kVp with no grid and high kVp with a grid). |
|              |        |              | 2. A 15% increase in kVp requires a 50% decrease in mAs in order to achieve the same exposure. | 2. The 15% rule is less reliable as the factors that affect the required mAs adjustment are patient thickness and the amount of mAs change required per kVp. |
| Carroll³³    | 1. 15% rule | Description of the system(s) | 1. A 15% increase in kVp requires a 50% decrease in mAs in order to achieve the same exposure. | None stated in article. |
|              |        |              | 2. Half value layer | None stated in article. |
|              |        |              | 3. Optimum (fixed) kilovoltage technique | None stated in article. |
|              |        |              | 4. Variable kilovoltage technique | None stated in article. |
|              |        |              | 5. AEC | None stated in article. |

(Continued)
| Author/Paper | System | Study Design | Description | Limitations |
|-------------|--------|--------------|-------------|-------------|
| Schueler34  | 1. 10 kVp rule | Description of the system(s) | ‘An increase of 10 kVp is equivalent to doubling the milliampere-seconds’. (p. 732) | implants are covering the detector. |
| McLean and Targett35 | 25%/cm rule | Water bath used to simulate a patient. The mAs needed for 1 cm increase in water depth was measured. No grid was used for 50–70 kVp and a grid used for 70–117 kVp SID = 100 cm. | Every cm increase of patient thickness requires a 25% increase in mAs. | It only works for a small range 60–100 kVp | It works for most radiographic situations. Exact adjustment varies a few percent, which has a negligible effect on image quality |
| Fauber36    | 1. 15% rule | Description of the system(s) | 1. A 15% increase in kVp requires a 50% decrease in mAs in order to achieve the same exposure. | 1. None stated in article. |
|             |        | 2. AEC | 2. A radiation detection device is placed in front of or behind the image receptor and measures the residual X-ray beam. When sufficient X-rays have reached the detector the beam is stopped. The AEC only controls the time factor so kVp and mA still need to be set. | The AEC requires correct centring and detector selection, as incorrect centring and/or detector selection will result in an over- or under-exposed image. The AEC cannot distinguish between scatter and primary beam so wide collimation will lead to premature automatic cut-off. |
| Bontrager37 | 1. 15% Rule | Description of the System(s) | 1. A 15% increase in kVp requires a 50% decrease in mAs in order to achieve the same exposure. | 1. None stated in article. |
|             |        | 2. AEC | 2. ‘These systems provide automatic termination of exposure time when sufficient radiation (exposure) is received by the selected ionisation chamber’. (p. 36) | 2. None stated in article. |
| Eastman38   | 1. AEC | Summary | 1. The AEC uses ‘either a photocell or ionisation chamber … to terminate exposure when sufficient remnant radiation has reached the receptor’ (p. 202). | 1. None stated in article. |
|             |        | 2. Body habitus technique | 2. There is a chart for each body type (hypersthenic, sthenic, hypostenic, or asthenic) and the patient is categorised as one of these types and the corresponding chart is consulted. ‘Both kVp and mAs vary’ (p. 202). | 2. None stated in article. |

(Continued)
HVL lies between 3.3 and 3.8 cm so it is difficult to determine which of these is correct. A HVL of 3 cm provides the basis of the 25% rule. The 25% rule provides a method for adjusting mA, s, or mAs in response to variations in patient thickness. The 25% rule states that a 25% increase in mA, s, or mAs is required for each centimetre the patient is greater than the ‘average’. This is more of a guideline as it only works for radiographic situations (low kVp with no grid and high kVp with grid) and is an average of values that deviate from this by 2–5% depending on the kVp. Manufacturers incorporated this rule in the construction of their systems by making the time and/or mA factor(s) increase by a factor of 25% simplifying the job for the radiographer.

The 15% rule describes the relationship between kVp and mAs. The 15% rule states that a 15% increase in kVp requires a 50% reduction in mAs to achieve the same exposure. This guideline only works for thicknesses of less than 15 cm and kVp less than 100 and variation from this will result in a 5% error which is important as it amounts to ~25% exposure difference. The 15% rule lacks accuracy across a wide range because the change in mAs required is affected by the mAs change per kVp and patient thickness.

Enright devised a simple method for finding the mAs required for a range of patient thicknesses. It was based on the linear logarithmic relationship between mAs and anatomy thickness based on the 25% rule. Comprehensive charts

The 25% and 15% rules are useful guidelines for exposure adaptation but require some calculations in order to find the required values. Comprehensive systems have been developed in the form of charts, which adopt these rules as a basis for their systems of exposure adjustment and minimises the calculations required. These are the ‘disc system’, the unit step radiography and the DuPont Bit System.
The ‘disc system’ adjusts numerous exposure parameters providing a more comprehensive system of exposure adjustment. This system involves two discs, the first focuses on the adaptation of exposure parameters (kVp, mA, s) to the variation in patient weight as well as being able to compensate for a change in one of the parameters through a change in another. The second disc looks at the parameter required to produce a diagnostic image with a certain tube unit, grid, film/screen combination and patient thickness. This system is much better than those mentioned above as it looks at how different factors affect the exposure parameter required as well as how to compensate for a change in the exposure parameters.

Unit step radiography is an early system of exposure adjustment designed to adapt technique to changes in film speed, screen speed, target-to-film distance, single-phase or three-phase power supplies, half wave or full wave rectification and the numerous patient variables. It adjusts exposure factors to compensate for changes in anatomy thickness by assigning each centimetre an exposure value scale (XVS) value as well as assigning the values of kVp, mA and time XVS values. An optimum exposure will be selected if the total XVS values of the exposure parameters equal the XVS value of the anatomy being imaged. However, this system fails at the extreme ends of the kVp range.

The DuPont Bit System is another comprehensive exposure adaptation system. It covers most of the factors and parameter adjustments that the ‘disc system’ performs and also takes into account pathology. The Bit System assigns ‘bits’ to a wide range of values for each parameter that could affect the residual beam. A change in the bit value of one parameter can be compensated for by a change in another parameter(s) by the same number of bits to produce an image of equal OD. A change in 0.2 ‘bits’ corresponds to the change required in the parameter for a visible change in the image and a change in 1 ‘bit’ corresponds to a doubling or halving of the exposure.

Technological approaches

There has also been the utilisation of technology in the selection of exposure parameters. Some of the systems, such as the unit step system described above, have been incorporated into the computer programs that speed up the exposure selection process. The X-ray system itself has also been improved through the addition of the automatic exposure control (AEC) system, which has direct control over the exposure being produced.

The AEC is designed to terminate the X-ray beam when a sufficient amount of exit beam is detected; this is determined by the mA and exposure time values. The AEC provides a quick and easy solution for adjusting radiographic exposure to patient thickness as it aims to give just enough exposure to produce the set image density. However, if the anatomy is not positioned over the AEC chambers, the wrong AEC chamber is selected or the wrong bucky selected, then the resultant image will be incorrectly exposed. Also the AEC is limited to bucky examinations and non-bucky examinations still require the use of manual exposures.

Several articles described and provided the code for computer programs which use formulas to calculate exposure adjustment factors. It is designed to request information about the examination to be undertaken and then provide a set of exposure parameters in return. The program by Markivee et al. is based on a modified version of unit step radiography and his initial clinical testing found that it was well received by the radiographers.

OD was a way to measure image quality in film/screen radiography. This value was also used as a way to determine the quality of the radiographs. An OD of 1.3–1.5 was deemed diagnostic and the techniques were assessed on their ability to produce or maintain this OD value. This measure of image quality is not applicable to digital radiography, particularly when viewing images on the monitor, so a new measure needs to be considered. Detector dose indices were developed for digital radiography which measures the amount of radiation that interacts with the detector and would provide a suitable substitute for OD.

The systems described above are systems for exposure adaptation. These systems rely on the optimal parameters for an ‘average’ person as a baseline to work from. However, a problem arises when classifying an ‘average’ person, as the ‘average’ varies depending on the sample selected, such as the world population or only females. A considerable amount of research has gone into finding the set of parameters that provides a diagnostic image with minimal patient dose. This research is valuable for the construction of exposure charts that the exposure adaptation system works with, allowing selection of patient-specific exposure parameters. The DuPont Bit System could provide a good basis for the construction of a digital radiography-specific radiographic exposure adaptation system.

Discussion

Several different systems have been developed to assist radiographers for variations in patients. There is the 25%
The literature has shown that it is possible to create a program that integrates a system of exposure adjustment so that radiographers can quickly input the factors known and get an optimal set of exposure parameters. Thus, once a digital-specific system of exposure adaptation has been developed, it should be extended into an electronic form allowing it to be easily accessible and increasing the likelihood that it will be used. It could be a useful tool both in the university, as a teaching tool and in the workplace as a patient optimisation tool.1

Conclusion
There are no studies examining the efficacy of exposure adaptation systems designed for film/screen radiography with digital technology, nor is there any describing a system made for digital radiography. Film/screen radiography has been almost completely replaced by digital radiography creating a need for a suitable method of exposure adaptation. Thus, future research should test whether the existing comprehensive exposure adaptation systems are applicable to digital radiography.8

Conflict of Interest
The authors declare no conflict of interest.

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