Optimizing image quality at constant effective dose by adjusting tube voltage for lumbar spine radiography using a flat panel system.

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Aims and objectives

Since the introduction of digital radiography, research has been performed to assess the optimal image acquisition parameters for an adequate image quality (IQ) and low as possible patient dose [1]. Important image acquisition parameters are tube potential (U) and tube charge (Q), which are set by the radiographer either by hand or by automatic exposure control (AEC). However, U and Q do not have a straightforward relation with measures of image quality and radiation dose. In general, Q is proportional to any dose measure. With increasing U the detector dose is kept constant by decreasing Q, which will decrease effective dose, because the fraction of low energy photons that is absorbed in the patient is smaller [2], but this may compromise image quality due to reduced contrast in the absorption of high energy photons.

Geijer et al and Uffmann et al found that IQ is best at low U when the effective dose (E) is kept constant for lumbar spine and chest imaging respectively [3], [4]. IQ was assessed by visual grading analysis (VGA) and measurement of the image quality figure (IQF) using a contrast-detail phantom. Geijer et al found no differences in between VGA and CD-phantom results.

Lanca et al and Allen et al found that increasing U with 10 kV and halving Q, known as the ‘10 kV-rule’, will lead to a reduced effective dose and equivalent perceived image quality of pelvic and chest images respectively [5], [6]. They assessed IQ by means of VGA. Their results suggest that the optimal U would be high because increasing U yields similar IQ at lower effective dose, which seems to be contradicting Geijer et al and Uffman et al. The 10 kV rule has its basis in the power relation of tube potential with exposure and is valid over a limited range of tube potential [7]. Lanca et al found that it does not appear to be valid for high Q-values.

A general model of the relation between input parameters (U, Q, etc) and outcome parameters IQ and E would provide a transparent means to optimize for IQ and E. Geijer et al evaluated the effects of input parameters on IQ and E using factorial analysis and visual grading analysis, and concluded that the optimal tube potential should be reduced to 60 kV [8]. Instead of Q they used speed as input parameter which should actually not be used in digital radiography [9].

In this study we developed an empirical analytical model of the relation between input U, Q and output IQ and E using a contrast-detail phantom in a lumbar spine set up. Using this model the optimal U at constant effective dose will assessed as well as the 10 kV-rule.

Methods and materials

Radiographic setup
For this study a Samsung DR XGEO GC80 with a flat panel detector (a-Si TFT / CsI) mounted in a bucky table was used. The system had a grid with ratio 10:1 and 215 lines/
inch. Focus detector distance was 125 cm. The standard post processing parameters were used. Focus size was small. The phantom consisted of 20 cm polymethylmethacrylate (PMMA), which has similar attenuation as the Alderson-phantom [8]. A contrast-detail phantom CDRAD 2.0 was placed at 10 cm depth [10]. See Figure 1. The field size was 37.1 x 36.0 cm². CDRAD analyser v2.1 program was used to evaluate the images and compute the IQFinv value. A high IQFinv value indicates a good image quality. Dose was measured with a calibrated DAP-meter mounted below the x-ray tube at field size 45.5 x 20.0 cm². This value was used as input to PCXMC 2.0 software which was used to estimate effective dose [11].

The standard tube potential and tube charge setting was 77 kV and 20 mAs with AEC. Therefore IQFinv and effective dose values were estimated for tube potentials from 60 to 90 kV with increments of 5 kV and tube charges from 8 mAs to 20 mAs with increments of 2 mAs and no AEC.

Model
The effective dose E is proportional to the tube charge Q at constant tube potential U. Therefore the E divided by Q can be modeled as a power function of U:

\[ \frac{E}{Q} = a \cdot U^b \]  

For all measured combinations of E and Q, first E divided by the respective Q were calculated and then averaged. The parameters a > 0 and b >0 were estimated by fitting the averages of E/Q with the tube potential using Microsoft Excel version 2007.

The inverse image quality figure IQFinv is approximated as a function of tube potential U and tube charge Q by a second order function:

\[ \text{IQFinv} = C_u \cdot U + C_q \cdot Q + C_{uu} \cdot U^2 + C_{uq} \cdot U \cdot Q + C_{qq} \cdot Q^2 + C_0 \]  

The parameters cxx were estimated using matlab R2013b. Given the data, this model is only valid for 60 kV < U < 90 kV and 8 mAs < Q < 20 mAs.

Combination of these two equations gives the relation of the image quality figure with the tube potential given and effective dose:

\[ \text{IQFinv} = C_u \cdot U + C_q \cdot \frac{E}{Q} \cdot a \cdot U^{b-1} + C_{uu} \cdot U^2 + C_{uq} \cdot \frac{E}{Q} \cdot U^{b-1} + C_{qq} \cdot \left( \frac{E}{Q} \right)^2 \cdot U^{-2b} + C_0 \]

By plotting this formula the tube potential where the image quality figure is highest when effective dose is kept constant was visually assessed.
Images for this section:

Fig. 1: Radiographic set up.

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Results

In figure 2 the effective dose per tube charge is shown. The curve is the best fit of formula 1 with $a=3\cdot10^{-9}$ and $b=3,36$ ($R^2=0,99$). E/Q is increasing with increasing tube potential.

In figure 3 IQFinv-values are shown. The plane is the best fit using formula 2. The mean deviation of the modeled IQFinv to the measurements is 0,21. The IQFinv is increasing with increasing $U$ and $Q$.

In figure 4 curves are shown for IQFinv at constant effective doses.

In figure 5 curves are shown for effective dose at constant IQFinv-values. The range of the curves is limited because the model is only valid in the measurements range.

Images for this section:
**Fig. 2:** Effective dose per mAs for tube potentials from 60kV to 90 kV. The solid line is a fitted power function (R² = 0.999)

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**Fig. 3:** IQFinv as function of tube charge and tube potential. The plane is the best fit of a second order function. Higher IQFinv values indicate better image quality.

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Fig. 4: IQFinv values at constant effective dose. The recommended setting (Q= 20 mAs, U= 77 kV) yields E=0.12 mSV. Higher IQFinv values indicate better image quality.
Fig. 5: Effective dose at constant IQFinv values.

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Conclusion

The model fit to the effective dose is well described by a power function. Caution should be taken to extrapolate to other situations. E/Q is higher for higher tube potentials. For the fit of the IQFinv-model formula 2 the average absolute deviation is less than 10% of the lowest IQFinv value and less than 5% on average, which justifies the use of this model. For the lumbar spine set up Geijer et al showed that the image quality is best at low tube potentials at constant effective dose. Our results show that the image quality increases when the tube potential is increased and the tube charge is adjusted accordingly to keep the effective dose constant (see figure 4). However, the effect is weak and the range of tube potentials is smaller than Geijer et al investigated. Figure 5 shows a similar trend, when a similar IQ is required the effective dose is lower at higher tube potentials. This difference may be explained by different detector technology as well as image processing software which optimizes image quality, and should be further investigated.

In conclusion, for the set-up used here, the optimal tube potential, to either obtain a better image quality at similar effective dose, or to obtain a lower effective dose at similar image quality, should be higher than the standard tube potential of 77 kV.

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References