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IMPROVEMENT OF CT SCAN QUALITY BY REDUCING EFFECTIVE DOSE

Abstract: *One of the main tasks of CT scanner design is to obtain enough quality of image and to reduce effective dose of X – ray radiation. These are inconsistent requirements because reducing of effective dose in the same time can degrade the image quality. The fact that can be used to reduce the dose while preserving the image quality is that different tissues absorb X-photons of different energy which allow us to make specific scanning procedures depending on the type of tissue being examined. This scenario includes use of different filter types, which change the X-ray spectra produced by the X –ray tube. In this paper two types of tissues are considered soft and cortical bone tissue. For X ray spectra simulation the SpekCalc software is used. This approach can be very helpful for medical doctor to reduce total effective dose during scanning procedure.*

Keywords: *CT scan quality, Effective dose, X-ray tube filter*

1. Introduction

One of the most common methods in medical imaging is computerized tomography (CT). The methodology includes use of X-ray radiation and represent very powerful technique in diagnostics, especially for cortical tissue and other non-soft tissues. The method is based on the attenuation of X-photon beam. The method is very useful but in the same time, it is one of the most significant contributors to X-ray exposure during life. CT scanning contributes the most to collective dose from exposures from medical imaging, both due to the relatively high dose per exam and to the increase dose of this modality. CT examinations make about 60-70 % of the dose from radiological examinations in developed countries.

Further research into the complex relationship between radiation exposure, image quality, and diagnostic accuracy should be encouraged, in order to establish the minimum radiation dose necessary to provide adequate diagnostic information (Mayo, John R., John Aldrich, and Nestor L. Müller.2003).

Protection of patients during scanning procedure is the main requirement during imaging procedure and design of CT devices. One way to minimize radiation dose is to better understand mechanisms of dose absorption and factors like construction of X-ray device, CT detector characteristics and patient tissue properties. Dose reduction can be achieved using appropriate filters (Lai, N. K., Liao, Y. L., Chen, T. R., Tyan, Y. S., & Tsai, H. Y. 2011). and (D.J. McLaughlin, R.B. Mooney, 2004). suitable reconstruction algorithms (Lee, S. H., Kim, M. J., Yoon, C. S., & Lee, M. J.2012) or special mode of X-ray source operation (Lee, Ting-Yim, and Rethy K. Chhem. 2010).

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2. Computer tomography

CT is a non-destructive method for characterizing 3D objects by using X-ray radiation. This method is based on the differences in attenuation coefficient of X-ray beams for various materials and tissues. The final result is a grey level CT image where corresponding grey level is proportional to attenuation coefficient.

CT medical imaging includes exposure of the object of radiation at one side and detecting attenuated radiation at the other side of the object and this procedure is repeated from more than one direction. The next step is image reconstruction from the projection by using a number of algorithms. These techniques are mainly based on solving systems of integral equations which are formed as a result of total attenuation of the radiation beam from the source to the detector. Attenuation of monochromatic X-ray beam passing through the homogenous materials is given by the relation:

$$I = I_0 e^{-\mu d}$$

where I_0 - is initial radiation intensity entering the material (number of X-photon particle per unit area in time), I- is radiation intensity exiting material of thickness d with linear attenuation coefficient μ. If a polychromatic X-ray source is used, it is necessary to take into account the fact that the attenuation coefficient is a strong function of X-ray energy. The complete solution would require solving the equation over the range of the X-ray energy (E) spectrum utilized:

$$I = \int I_0(E) e^{-\mu(E)d} dE$$

Different materials have a different attenuation coefficient values, which are very dependent of energy. Application of X-ray filter relays on this fact. The X-rays should be absorbed on the energies which contribute the most to absorption dose during scanning procedure.

2.1. X-ray tube

X- ray radiation is created during interaction of high energy electrons with material, during which kinetic energy of electron is converted to electromagnetic radiation. This is realized inside the X-ray tube by applying high potential difference between the electrodes (cathode and anode). Electrons released from the cathode are being accelerated inside electric field formed due to the potential difference and hit the anode, creating the X-radiation by converting their kinetic energy into electromagnetic. Most of the interactions will only release heat in the collisions of high speed electrons with the electrons of the target material, which limits the number of X-photons which can be produced in the time interval. Only in very small number of cases (around 0.5% of total number of electrons) the loss of energy in the collision can be significant and sufficient for the creation of high-energy X-photon. This will occur when electron approaches very closely to the strong electrical field created by the positively charged nucleus of the target atom. In this case, electron strongly decelerates and loses its kinetic energy which is then converted into X-rays. Radiation formed in this way is known as Bremsstrahlung.

The amount of energy which electron loses during the Bremsstrahlung, and consequently the energy of created X-photon, depends on the distance of the electron from the nucleus since the Coulomb force varies strongly with the distance. For large distances from the nucleus Coulomb force is weak, which results in a small energy loss of electron and hence creation of low energy X-photon. Probability for this kind of interaction is relatively high. If the electron interacts closer to the nucleus, more kinetic energy is lost and higher energy X-photon is emitted.

Probability for this event is lower. Direct collision of the incoming electron with the nucleus would cause complete energy loss and hence emission of the highest energy X-photon, but the probability of such an event is very low due to the small cross-section of the nucleus. Due to the nature of X-ray production, it becomes obvious that X-ray tube produces polyenergetic photons. Highest energy is determined by the applied voltage, and lowest by inherent and added filtration of the beam.

Besides Bremsstrahlung which gives polychromatic radiation, X-tube emits also monochromatic, so called characteristic radiation. Energy of this monochromatic component depends on the anode material, or more precisely energy levels of K, L and M electron shells in the atom of this material.

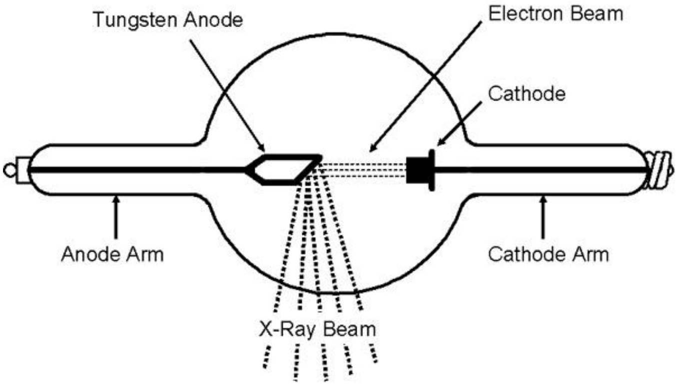

Figure 1. X-ray tube as part of CT system

The x-ray generator provides the power necessary to produce x-rays within the x-ray tube, and permits the selection of x-ray energy, x-ray quantity, and exposure time. The circuit consists of a high-voltage transformer, rectifiers to change the AC current to DC, and a filament, which produces the current in the X-ray tube. X-ray production is more efficient at higher voltages. The higher average voltage of three-phase circuit produce more X-rays per mA that can be obtained with a single-phase circuit with the same average current. Thereafter, the design of x-ray generator has developed by several investigators such as constant potential generators (1960's) and high-frequency generators (1980's). High-frequency inverter generator which has been available for the past 10-15 years, are becoming the universal choice for diagnostic radiographic systems, which improve the accuracy of diagnostic examinations, and protect the X-ray tube and patient.

3. Results

In this paper the different type of filter for X-ray tube is considered. We take into account two type of tissue during scanning procedure: the cortical bone tissue and brain tissue. The corresponding linear attenuation coefficient and its energy dependency are shown on the Figure 2. for brain and, on the Figure 3. for cortical bone tissue. We can notice that attenuation and in the same time absorption of X-ray beam is very prominent in the low energy part of the spectra and dramatically decrease for higher energies. This low-energy area is where we expect that majority of photons will be absorbed thus increasing the dose to the patient, while not contributing to the quality of the image at all, since they cannot reach the detector. The primary task of the additional filtering on the X-ray tube is to remove from the beam precisely dose low energy photons, which are of no value for diagnostics and at the same time increase the dose to the patient significantly.

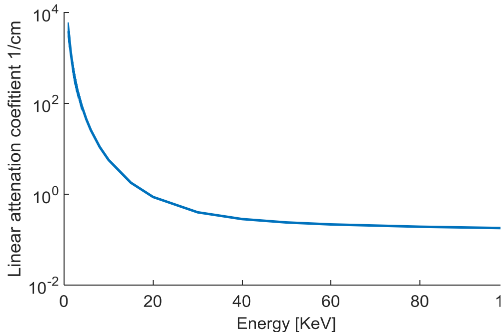

Figure 2. Energy dependent attenuation coefficient for brain tissue

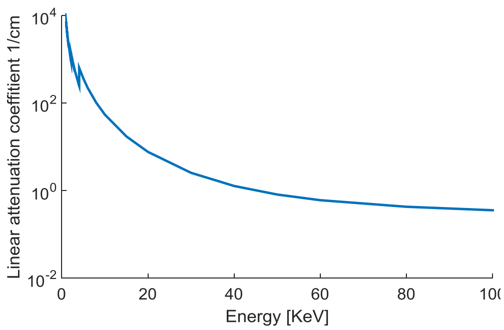

Figure 3. Attenuation coefficient for cortical bone tissue dependent of energy

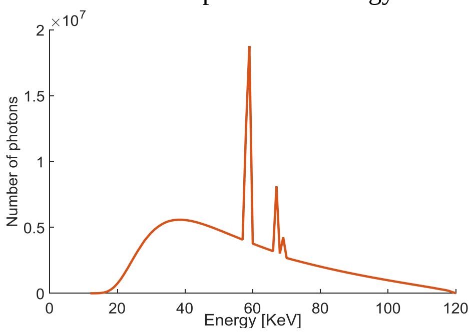

Figure 4. X-photon distribution with 0.24 mm of copper filter in unit: Number of photon per keV ·cm^2 ·mA·s

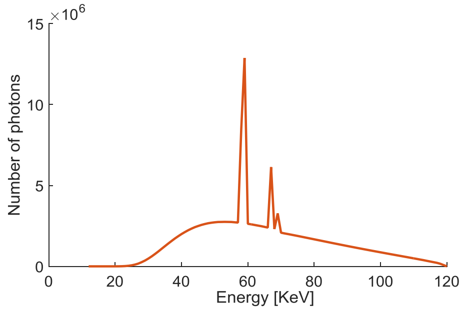

Figure 5. X-photon distribution with 0.3 mm Copper filter in unit: Number of photon per keV ·cm^2 ·mA·s

Effective dose D of X-ray radiation in considered medium of thickness t, exposed by radiation is in direct correlation with attenuated part of the beam. Actually, we can write:

$$D \sim \int I_0(E)\left(1 - e^{-\mu(E)t}\right) dE$$

Using approximation $e^{-ax} =\approx 1 - ax$we can obtain simply formula:

$$D \sim \int I_0(E)\mu(E)t dE$$

The $I_0(E)$ represent initial energy of X-ray spectra. For this purpose, we generate spectra using SpectCalk software. During generating spectre profile although, other data it is necessary to define filter material and its thicknesses as input parameter.

The task of finding optimal material for filter is actually minimizing function given by relation (5). Minimization can be performed up to some threshold value only. Minimization of absorbed dose below this value leads to decrease in image quality. The exact threshold value (maximum filter thickness) will depend on the specific examination performed. Many factors have influence on this value like spectral characteristic of detector, material distribution, etc. In this study it was assumed that maximum of filtered part of the beam can be three times less than absorbed photons in the case without filtration. Copper is used as filtration medium material. This study shows that minimum exposure dose is obtained for 0.194 mm thick copper layer for brain tissue while for cortical bone tissue, that minimum is obtained for 0.1 mm of copper layer. The X-ray spectra for these cases are shown in the figure 3 and figure 4 respectively.

4. Conclusion

In this paper, we consider using varying thickness of copper as a material for X-ray tube filter. We assumed that optimal filter thickness is dependent on the tissue material observed by X-ray examination.

The effective dose is minimized for brain and cortical bone tissue. The effective dose is calculated using simplified model. The assumption is that dose is in correlation with absorbed portion of photons. The obtained result shows that effective dose is minimal for 0.194 mm of copper for brain tissue and 0.1 mm for cortical bone tissue. This result imply that the effective dose can be reduced by appropriate filtration taking into account specific tissue being examined.

In the future research different filter material combinations and tissue compositions will be considered.

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