Statistical Analysis to Establish the Relationship between Radiation Consumption and Energy Use for Medical X-rays

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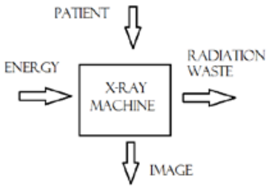
Abstract. Ways to determine how much radiation is actually used to produce an X-ray image have not been developed and this is an essential step for a complete life-cycle analysis (LCA) of medical imaging procedures. The work presented here was an exploration of a statistical method, based on image processing, of an actual X-ray image to determine how much radiation was used to create that image. The X-ray source, the interaction of the X-ray photons from source to target, and the interaction between photons and soft and hard tissue were simulated. An estimation of how much radiation was produced, and how much radiation was used was obtained. Also, the level of radiation absorbed by the patient was described here by using a correlation function between a non-filtered X-ray image and a filtered X-ray image. The complete work described in this paper presents basis towards a complete LCA on radiology imaging procedures.

1. Introduction

The main objective of this project was to analyze the relationship between inputs and outputs on an X-ray machine. The input in this case is defined as electric energy and the output as radiation.



The steps that were followed in order to achieve the objective were: design an experiment to obtain the relationship between the factors required to produce an X-ray; create a mathematical model of an X-ray source; and based on the interactions found in the experiment create a second model of X-ray photon interactions with different mediums.

The research effort was divided into the following steps:
1. Determine how the factors that can be modified during setup affect the input as well as the output. These factors are: the voltage applied to the X-ray tube, the electric charge on the X-ray tube, distance from the source to the target, and type of material being tested.
2. Create a mathematical model of the X-ray source, the medium of propagation, and the X-ray target.
3. Determine the radiation usage, to determine how much radiation was used and how much was wasted during an X-ray exam. This step will provide the means in order to determine the entire machine energy usage.

2. Experiment, Results, Discussion, and Significance

To determine the relationship between relevant factors on an X-ray machine, an experiment was performed using a two replicate general factorial with a level of significance of 0.05 tested at three levels of voltage (60, 75 and 90 KV), three levels of electric charge (10, 64 and 124 mAs), three distances (16, 28 and 40 in), and using three different materials (lead, copper and aluminum).

An analysis of variance indicates that voltage was a significant factor, and the interactions between electric charge-material, and distance-material were significant as well.

The experiment indicates that there was scatter radiation depending on the material and it was measurable. This will help develop a model of radiation absorption depending on a material density.

The model of the source was based on the breaking radiation equation

$$-\frac{dE}{dx} = \eta * R_A * k \int_0^{\epsilon_{ik}} \frac{d\sigma}{dk} * dk \qquad (1)$$

This equation was used to simulate the energy of individual photons coming from the source. The total amount of photons produced was calculated by using the electric charge on the X-ray filament and the thermionic emission principle which estimates the amount of electrons on a conductor that gain enough energy to become free electrons.

To model how the X-ray photons interact with the medium of propagation, measurements of the machine power consumption and radiation levels at different distances were plotted and compared to obtain an attenuation factor.

The best fit of the scatter plots shown in Fig. 1-2 was a power factor approximation. Averaging equation (2) for the complete machine power range indicates that the radiation level undergoes an attenuation given by the square root of the distance. This result was used to attenuate the radiation level of the simulated photon once it reached the target.

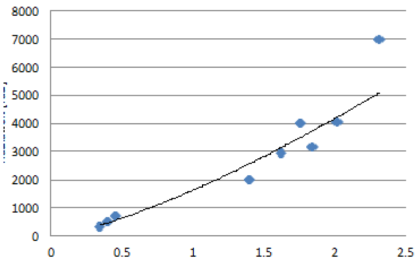


Fig 1 .Machine Power vs Radiation at 16 in from the source

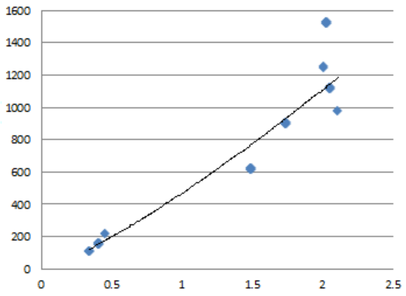


Fig 2. Machine Power vs Radiation at 28 in from the source

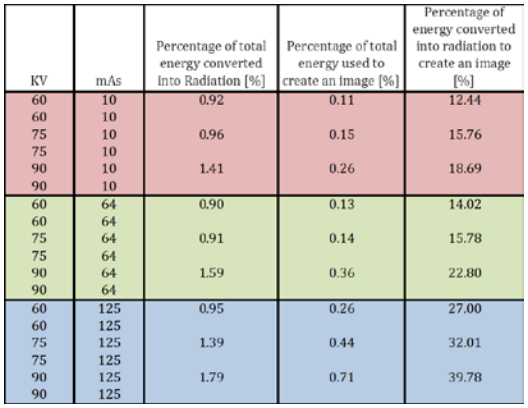
$$\frac{Radiation|_{@16in}}{Radiation|_{@28in}} = \frac{1635.3 * Machine\ Power^{1.35}}{468.15 * Machine\ Power^{1.24}} \qquad (2)$$

The last part of the simulation was to model how an X-ray photon interacts with the target. For this model, an actual X-ray image was broken into pixels and analyzed. A probability was assigned to each simulated photon so that the likelihood of that photon hitting a determined pixel on the image could be determined.

Since an X-ray image is gray-scale color based where a very white color indicates very high density material and very black is indicated low density material, a linear interaction probability between photon energy and material density was implemented, giving low energy photons very low probabilities of penetrating high density points, and higher probability if it were to be a high energy photon.

With this approach it is possible to establish how much of the total energy used to power the X-ray machine was actually used to produce an X-ray image. These results are shown in table 1.

Table: 1.
Results for Energy Usage on an X-ray image



KV	mAs	Percentage of total energy converted into Radiation [%]	Percentage of total energy used to create an image [%]	Percentage of energy converted into radiation to create an image [%]
60	10	0.92	0.11	12.44
60	10			
75	10	0.96	0.15	15.76
75	10			
90	10	1.41	0.26	18.69
90	10			
60	64	0.90	0.13	14.02
60	64			
75	64	0.91	0.14	15.78
75	64			
90	64	1.59	0.36	22.80
90	64			
60	125	0.95	0.26	27.00
60	125			
75	125	1.39	0.44	32.01
75	125			
90	125	1.79	0.71	39.78
90	125			

3. Conclusions

The model can be implemented on any image with results comparable to the ones shown in the previous section. In average it was found that approximately one percent of the energy used as an input for the machine was actually converted into radiation. Consequently only a fraction of the energy was used to create an image.

4. Acknowledgements

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