



LOCALLY FABRICATED METAL STEP WEDGE FOR QUALITY ASSURANCE IN DIAGNOSTIC RADIOLOGY

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ABSTRACT

The code of safe practice for the use of x-rays in medical diagnosis requires that each x-ray facility has an appropriate quality assurance program in radiation protection, to ensure accurate diagnosis, and to keep doses as low as reasonably achievable. This requires an in-house system of regular checks and procedures. This research has investigated and carried out some of these checks via the step wedge, fabricated by adopting the model of a standard aluminum wedge obtained from the radiology department of the Jos University Teaching Hospital (JUTH) using locally acquired metals. The wedges were exposed to x-rays and the optical densities of the processed films measured with a densitometer. The result indicates that standard equipment can be produced from locally sourced materials, as well as to investigate an alternative wedge material. The values of the both the local and standard aluminum wedges fall within range of the tolerance limit of $\pm 5\%$ (Rehani, 1995).

Keywords: Quality Assurance, Step wedge, Optical density, Tube current, Exposure time, Peak kilovoltage.

INTRODUCTION

Quality and efficiency of instruments and equipments to a required standard ensures maximum output performance. In the case of already in-use equipments, routine testing is necessary for its optimum performance to the required standard. Routine tests (Rehani, 1995) are of two categories:

- i. Tests that has previously been carried out as reference test and are repeated weekly, fortnightly, monthly, quarterly or annually.
- ii. Daily or operational checks, carried out each day the instrument or equipment is used.

These checks and tests ought to be executed in like manner if successive results are to be comparable. All these measures, combined with other carefully planned and executed procedures, are what lend credence and quality to any service performed, and are collectively known as Quality Assurance (QA). However, these tests would not be effective if, after discovery of defects and/or malfunctioning, corrective measures are not taken to address such. Hence, it is necessary to;

- i. Plan: map out the different steps that will be required in the QA program. This means identifying problems and proffering solutions.
- ii. Upgrade: take necessary steps to lift the standard of performance and service delivery.
- iii. Evaluate: check the status and rate of performance against preset goals, to know the progress achieved so far. All organizations require the implementation of a QA program at some point, even more so in the fields of medicine and engineering (Polleti, 1995).

Quality Assurance in Diagnostic Radiology

Ionizing radiation is the energy emitted as a result of naturally/artificially occurring radioactive elements, radioactive decay of unstable elements, collision of electrons with metal surfaces, and so on. Diagnostic Radiology is the medical applications of this radiant energy to improve health care, as in radiography, mammography, radiotherapy, and so on.

The main aim of diagnostic radiology is to produce a picture in the form of shadows of varying degrees of blackness (grayness) of particular anatomical structures, from which the Radiologist can infer any departure from normality based on the information (Meredith and Massey, 1977).

To effectively achieve this aim, all instruments and equipments used must be in excellent condition to ensure that the image produced is of good quality. This is the essence of quality assurance. The performance evaluation tests implemented in a QA program are divided into three categories viz: mechanical, radiological, and other checks. It has been established that sources of artificial radiation like x-rays and gamma rays employed in diagnostic radiology comprise the bulk of radiation to which patients, personnel and the general public are exposed (Stanton, 1967). This could be as a result of;

- a. The use of low performance x-ray machines.
- b. Carelessness of personnel in taking radiation safety measures such as the use of filters, cones, diaphragms, grids and lead aprons and gloves.
- c. Production of low quality images that would necessitate retakes, thus doubling or even tripling the radiation doses to which the patient is exposed.

- d. Inefficiency of personnel, for instance, when exposure factors appropriate to the examination are not selected, it may lead to the production of low energy photons of 30keV or less, that would be absorbed by the superficial layers of body tissue, and these low energy photons are more harmful.
- e. The low energy requirement of the screen film mammography for a good contrast and the requirement of the focal spot (Barnes and Frey, 1991).
This generates the need for the implementation of a quality assurance program that would address issues of radiation safety, output performance of x-ray machines, constancy of radiation output, x-ray film quality of the image produced, varying tube current, setting of the x-ray generator and line resistance (Rehani, 1995), which could impede the performance of equipments. These constitute some of the problems that this study has sought to address, and include:
 - i. Testing whether radiation output of the x-ray machine in the Radiology Department of JUTH is constant.
 - ii. Checking the control of the machine.
 - iii. Investigating the linearity and reproducibility of the tube current and exposure time, as well as any existing relationship between these two parameters and the optical density.
 - iv. Investigating whether or not local materials (aluminum) can be used to produce a standard step wedge, one that would produce results within the range of those produced by the control wedge, hitherto used at JUTH
 - v. Investigating possible cheaper alternative wedge material to aluminum that would produce the same results.
 - vi. The instrument of interest in carrying out the above mentioned checks is the step wedge, although a number of other instruments may be used, such as water/Perspex phantom, exposure meter (rad-check), and RMI multifunction meter (Rehani, 1995).
 - vii. A step wedge is a rectangular block of aluminum or some other metal, filed into steps of increasing thickness, usually 1-12-16 steps. Each step represents a level of density. The higher steps are denser, thus absorb more radiation than they transmit. The lower steps, on the other hand, are not as thick, and hence readily transmit radiation, absorbing none at all (Martins, 2007).

They can also be used to correct the heel effect, a variation in the intensity of x-ray beam along the anode-cathode axis, that would otherwise introduce large errors into measurements of skeletal density, (www.ndt.net/article/ct.2003/v22/v22.html).

Aluminum is used as a wedge material because it has good optical properties; the bare metal

has a high reflectivity for light, heat and electromagnetic radiation over a wide range of wavelengths. At the same time, high reflectivity means that there is little absorption of incident radiation. It is durable, flexible, corrosion-resistant, light, easily cast and machined, cheap and readily available, and has a low density of 2.698g/cm³. Because it is naturally soft in its pure form, aluminum is alloyed with another metal, in this case silicon (density $\rho=2.34\text{g/cm}^3$) to increase its strength (www.msm.cam.ac.uk/phase-transit/abstracts/m7-8.html).

The concept of using brass as a step wedge material is to enable comparison between the results of the two metals, to see whether or not brass could be used as a substitute material that would produce similar results, in the event that aluminum is not readily available. Brass has a density of 8.49g/cm³, and a shear modulus of 37GPa (giga pascal) ([www.ezoluk.com/Technical info/mpBrass](http://www.ezoluk.com/Technical%20info/mpBrass)).

MATERIALS AND METHODS

Construction

Both metals were obtained in the form of rectangular block of dimensions;
Length, L=21 cm, Width, W=5.7cm, Height, H=2.2cm

The construction work was carried out at the metal works department of Government Science and Technical College, Bukuru, Jos south, Plateau state. The metals were machined to square using the lathe machine, to smoothen out rough edges and to make the surface uniformly smooth throughout and of the exact dimensions of the control wedge. The thicknesses and heights of the steps of the control wedge were then measured using the vernier caliper, and their exact dimensions marked on the metal blocks with a pencil, to aid accuracy in cutting the steps. The aluminum block was placed on the tray of the milling machine, and very carefully following the marked lines, the steps were filed out, 16 steps in all dimension of each step. The procedure was repeated on the brass block.

Exposure

- i. Selection of factors: this was done with patient conditions in mind. That is, the exposure factors selected were factors that might have been used in an actual x-ray examination of a patient, say chest x-ray.
- ii. A control exposure was made at 66kV, 50ms, and 300mA on a 24x30cm cassette. After processing and drying, the control film was assessed on the view box. All the steps of the control and local wedges were visible, though the contrast was poor, while only the first step of the brass wedge was visible. This pointed to the fact that, due to its higher density, the brass wedge would require higher exposure factors, especially the kilo voltage. It also implied that to obtain a better contrast and thus a good optical density, the exposure factors of the aluminum wedges needed to be lowered.

- iii. A loaded 17x14cm cassette was placed on the bucky, a distance of 100cm from the tube target and the brass wedge placed on the left section of it. The beam was collimated over the wedge, and the remaining portion covered with sheet lead. Exposure was made at 70kV, 28ms, 571mA and 16mAs. The process was repeated three times while moving the brass wedge and covering the remaining portion, varying the values of the current (mA) and exposure time (ms), but keeping the mAs and kV constant. Thus four different exposures were made with the brass wedge on the same film.
- iv. Then using two different cassettes of the same dimension, a total of six exposures were made for the control and local aluminum wedges, with the factors 60kV and 12.5mAs kept constant, but the current and exposure time varied each time (20ms and 625mA, 22ms and 568mA, 25ms and 500mA, 28ms and 446mA, 32ms and 391mA).

- v. Processing: This was done in the dark room with only the safe lights on. The exposed films were removed from the cassettes and processed under the following predetermined conditions.

Measurement of Optical Density

The measurement of Optical Density (O.D), was carried out using the digital densitometer x-rite 3 31 nickel-cadmium (NiCad) battery operated (600/700mAh) densitometer of the radiology department of JUTH. For the constant 60kV films with the images of the aluminum wedges, the optical densities of the first, eighth, and sixteenth steps were measured. For the constant 70kV film with the images of the brass wedge, the optical densities of the second steps were measured, since only two steps were visible.

RESULTS AND DISCUSSION

The step wedge method of checking the constancy of radiation output does so in terms of optical density, which represents the total exposure reaching the film and producing the image. Presented below is the table of results obtained.

Table 1: Standard Aluminum Wedge - at 60kV, 12.5mAs

Step	Exposure Time (ms)	Tube Current (mA)	Optical Density (D)
1	20	625	2.13
	22	568	2.11
	25	500	2.11
	28	446	2.01
	32	391	2.02
8	20	625	1.23
	22	568	1.29
	25	500	1.36
	28	446	1.25
	32	391	1.20
16	20	625	0.51
	22	568	0.48
	25	500	0.45
	28	446	0.45
	32	391	0.43

Table 2: Local Aluminum Wedge-at 60kV, 12.5 mAs

Step	Exposure Time (ms)	Tube Current (mA)	Optical Density (D)
1	20	625	2.05
	22	568	2.04
	25	500	2.01
	28	446	2.03
	32	391	2.01
8	20	625	1.02
	22	568	1.04
	25	500	0.99
	28	446	1.01
	32	391	1.02
16	20	625	0.39
	22	568	0.35
	25	500	0.32
	28	446	0.33
	32	391	0.32

Table 3: Brass Wedge at 70kv, 16mAs

Step	Exposure Time (ms)	Tube Current (mA)	Optical Density (D)
2	28	571	0.28
2	40	400	0.62
2	50	320	0.73
2	71	225	1.25

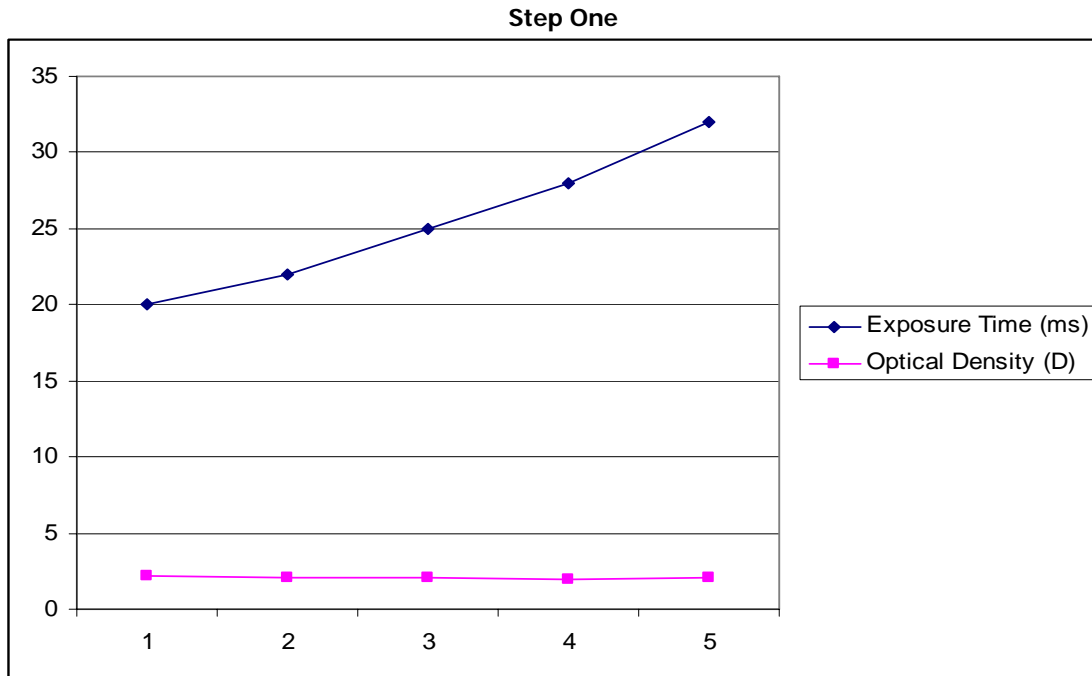


Fig. 1: Exposure time against Optical Density

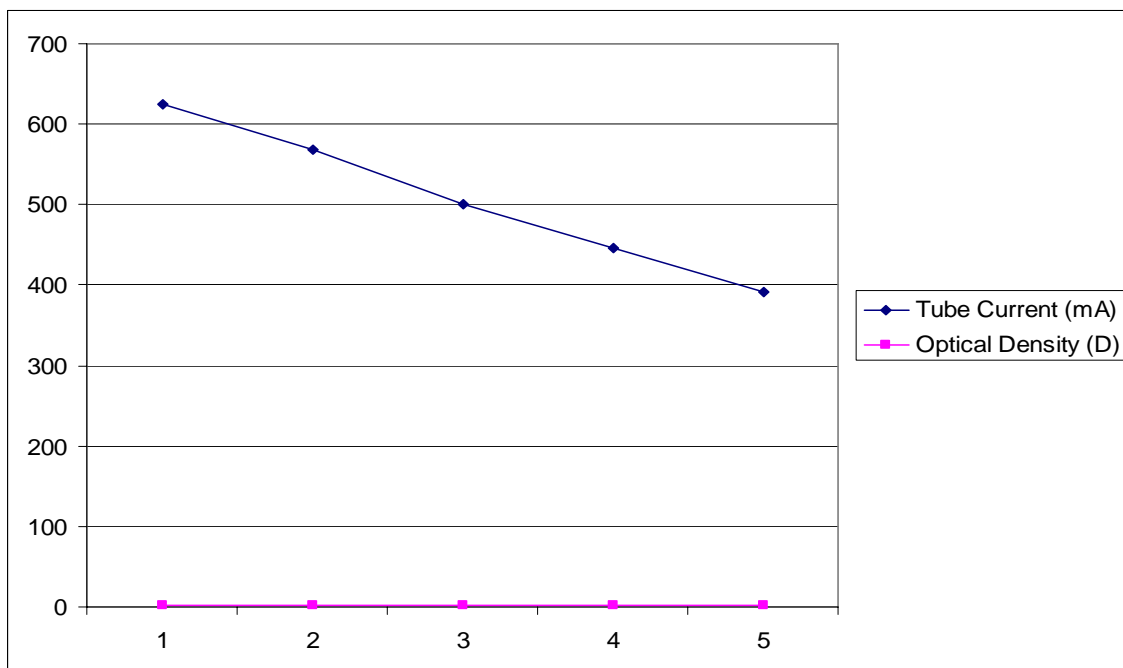


Fig. 2: Tube Current against Optical Density

Step Eight

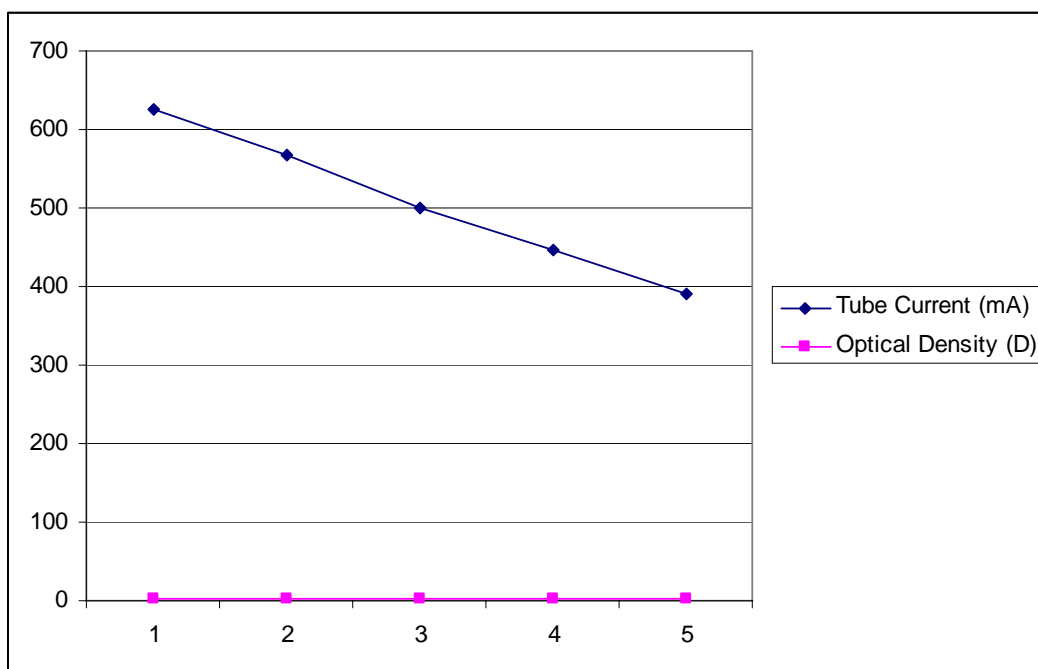


Fig. 3: Tube Current against Optical Density

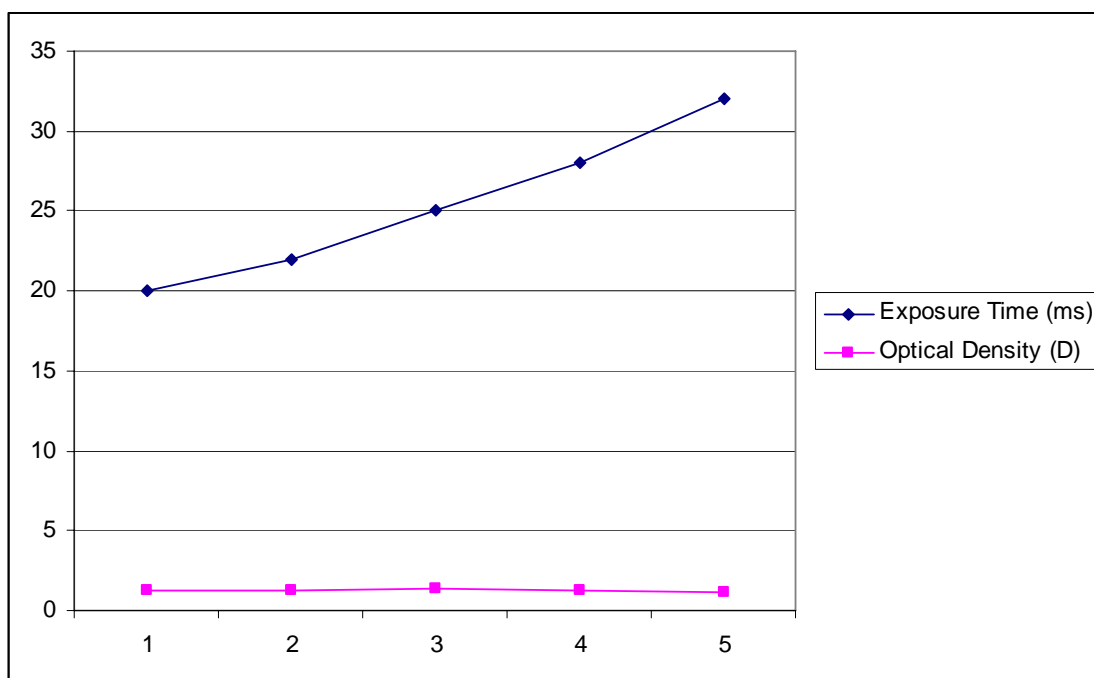


Fig. 4: Exposure Time against Optical Density

Step Sixteen

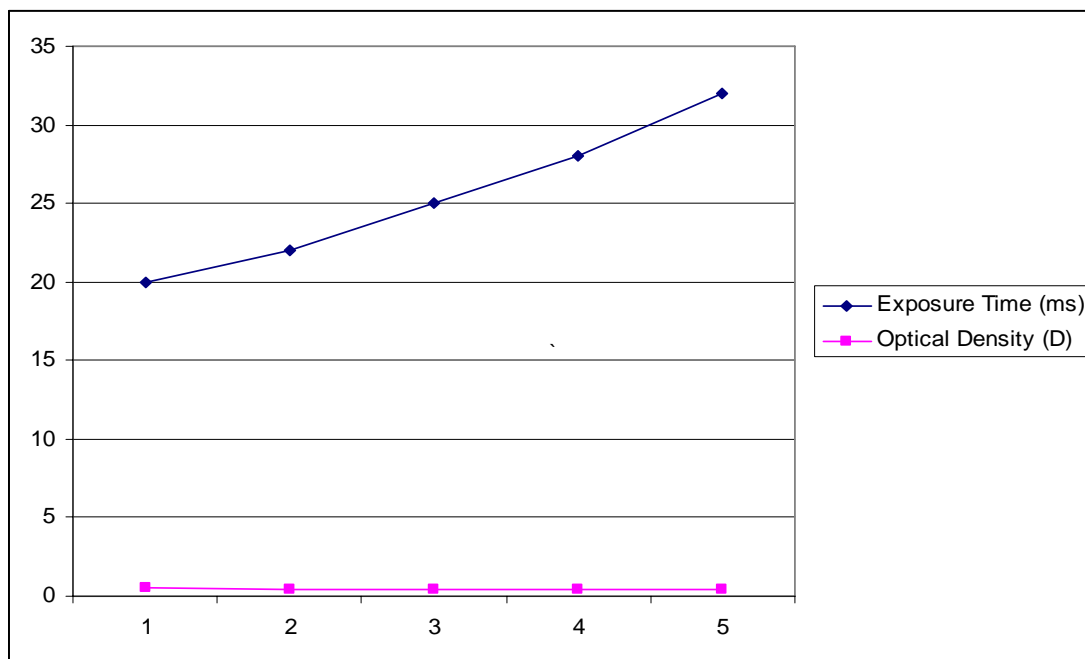


Fig. 5: Exposure Time against Optical Density

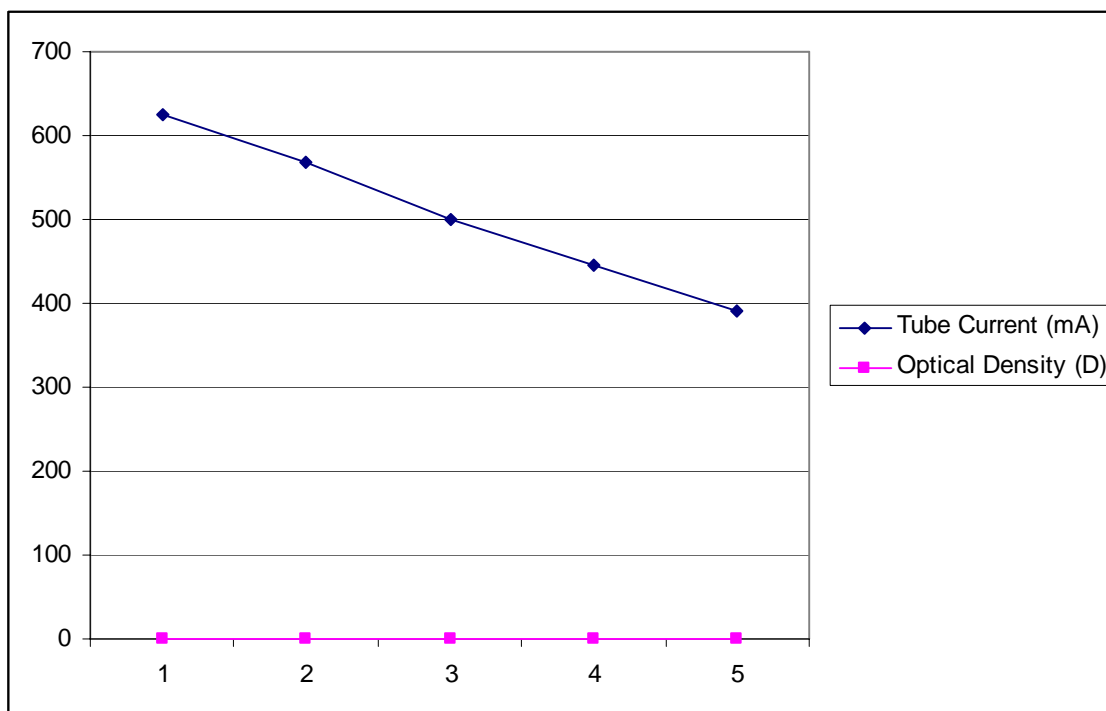


Fig. 6: Tube Current against Optical Density

The standard film serves as a reference image with which subsequent images are compared. It indicated that the exposure factors selected were within range, but that due to its higher density, the brass wedge would require higher exposure factors in order to produce an acceptable optical density. It also pointed out that, in order to obtain a better contrast and thus a good optical density, the exposure factors of the aluminum wedges needed to be lowered.

The exposure time and tube current are related by the equation $mAs = mA \times ms$
 Where; mA = tube current (milliampere), ms = exposure time (milli seconds), mAs = current/time combination (milli ampere seconds). Any missing parameter may be calculated from this relation, as some machines have no provision for certain factors to be selected, but they can be calculated from those available and selected.

From the results, it implies that significant changes in either mA or ms can cause drifts in the optical density, especially since they both affect the degree of film blackening (mA) determines the number of electrons given off from the filament and thus the intensity of

$$\text{Contrast, } C = D_2 - D_1$$

The average densities for each of the steps measured for both local and control aluminum wedges are calculated thus;

Local Aluminum wedge

$$1^{\text{st}} \text{ step - O.D}_{(\text{ave})} = (2.05+2.04+2.01 +2.03+2.01) \div 5 = 2.028\text{D}$$

$$8^{\text{th}} \text{ step - O.D}_{(\text{ave})} = (1.02+1.04+0.99+1.01+1.02) \div 5 = 1.016\text{D}$$

$$16^{\text{th}} \text{ step -O.D}_{(\text{ave})} = \{0.9+0.35+0.32+0.33+0.32\} \div 5 = 0.342\text{D}$$

Standard Aluminum wedge

$$1^{\text{st}} \text{ step - O.D}_{(\text{ave})} = (2.13+2.11+2.11+2.01+2.02) \div 5 = 2.076\text{D}$$

$$8^{\text{th}} \text{ step - O.D}_{(\text{ave})} = (1.23+1.29+1.26+1.25+1.20) \div 5 = 1.246\text{D}$$

$$16^{\text{th}} \text{ step - O.D}_{(\text{ave})} = (0.51+0.48+0.45+0.45+0.43) \div 5 = 0.464\text{D}$$

Predictably, the optical densities of the higher steps are less than those of the lower steps. This is due mainly to attenuation (removal of energy) of the x-ray beam by the wedge material, especially the low energy photons, because of the increase in thickness of the wedge material, X, with increase in the number of steps. Thus most of the lower energy photons are absorbed by the wedge material, and very few high energy photons actually reach the film and form the image, regardless of the uniform intensity of the beam.

Hence x-rays are, more readily transmitted(without any change in photon energy) through the lower steps because they have less distance to travel and fewer atoms of the wedge material to encounter before they reach the film and form the image. A contributing factor is the atomic number, Z, as well as the density, ρ, of the wedge material. These determine the extent to which the

$$I_T \propto V^2$$

$$I_w \propto V^5 \text{ (Stanton, 1967)}$$

Where;

I_T = intensity emitted by tube (incident), I_w = intensity reaching the receptor (transmitted), V= tube potential

This means that changes in the potential can cause drifts in the beam intensity, and thus significantly influence radiation dose and image quality, as well as after the film density. But since the voltage was kept constant during this experiment it is safe to consider the beam intensity uniform.

Besides the reasons stated above, the voltage was kept constant in order to check the regulation of the machine. That is, the constancy of generator voltage with changes in tube current. A generator with good regulation maintains its voltage output for larger changes in the tube current than one with bad regulation (Hay and Hughes, 1978). Change of voltage with change of current is not acceptable in radiology because it causes changes in contrast of the image obtained, thus affecting image quality, as well as leading to increased radiation dose (Martin, 2007). The voltage was varied, as in the quality control test for the assessment of the kVp, then the difference in optical density between any two steps measured would give an indication of the constancy of beam quality over time.

the x-ray beam, while ms determines the interaction time between the x-ray photons and the atoms of the wedge). The difference in densities between any two steps for the same exposure factors represents the contrast (for that region of the film).

wedge material absorbs photons of the x-ray beam, thus contributing to the overall optical density of the film. Absorption/attenuation coefficient generally increases as photon energy decreases.

Furthermore, inappropriate selection of exposure factors could result in increased optical density but poor image contrast and resolution or vice versa. This was demonstrated via the reference film, where at 66kV, high values of optical density were obtained, but the image contrast was poor, the lower steps of the aluminum wedges were barely visible, whereas for brass, a good contrast was obtained, but only one step (the lowest) was visible, implying low optical density. The x-ray intensity emitted by the tube is known to vary approximately as the square of the peak kilo voltage KVp, while the x-ray intensity reaching the receptor after the beam has traversed the wedge varies approximately as the fifth power of the KVp.

CONCLUSION

To achieve the correct balance between patient dose and image quality, it is necessary to understand the way in which the images were formed, and to know the factors that influence the image quality and the radiation received by the patient, so that appropriate options can be selected.

Achieving this balance requires the skill, experience, and extensive knowledge of a Physicist, thus influencing the choice of this research project which via the step wedge exposure method, succeeded in

1. Checking the constancy of radiation output of the x-ray machine of the Radiology department of JUTH.
2. Checking the regulation of the machine.
3. Investigating the linearity and reproducibility of the tube current and exposure time, as well as their combination.

4. Investigating and establishing a linear relationship between the optical density and exposure time, as well as between the optical density and tube current from the graphs plotted, where the optical density can be predicted given the values of the slope and intercept, which will help Radiographers in their selection of exposure factors suitable for radiological examinations that will provide a good image contrast.
5. Proving that a standard step wedge (or at least, as close to standard as possible) can be obtained from local materials, to reduce the cost of importing one from developed countries.
6. Investigating an alternative wedge material to aluminum that would mimic clinical imaging situations, in this case brass, which proved to be a bad wedge material because it required higher radiation dose due to its

higher atomic number and density, and which in real imaging situations, would imply harmful radiation over dose to the patient.

If the main images had differed markedly (negatively, of course) from the reference image without any change in film/screen combination or processing conditions, then the differential diagnosis for this inconsistency would be a fault with the x-ray machine, which can then be sought and corrective measures taken. Also, from the results obtained, the values of the optical densities of both the local and control aluminum wedges fall within range of the tolerance limit of $\pm 5\%$ (Rehani, 1995). Furthermore, this study proves that dose reduction without regard for image quality could produce images that are inadequate for diagnosis, and must be avoided. It thus gives an indication of the exposure factors to be selected for the most common radiological examinations (chest, and limb), which have relatively low densities.

REFERENCES

- Barnes G.T. and Frey G.D. (1991). Screen-film mammography. Imaging considerations and medical physics responsibilities Proc. Of SEAAPM spring Symposium, Columbia, South Carolina, April 6 1-13 and 119.
- Hay, G.A and Hughes, D. (1978). Basic First Year Physics for Radiographers. Bailliere-Tindall Publishers.
- Martin, C.J. (2007). Optimisation in General Radiography www.bijj.org/2007/2/e18
- Meredith, W.J and Massey, J.B. (1977). Fundamental Physics of Radiology. John Wright and Sons Ltd.
- Polleti, J.L (1995). Guide lines for Quality Assurance in Radiation Protection for Diagnostic X-ray Facilities. National Radiation Laboratory, NRL.www.moh.govt.nz/publications/l_995-1.pdf.
- Rehani, M.M. (1995). Diagnostic Imaging Quality Assurance. Jaypee Brothers Medical Publishers.
- Stanton, L. (1967). Basic Medical Radiation Physics. www.ezoluk.com/technical info /mpbrass.html
www.msm.cam.ac.uk/phase-trans/abstracts/m7-8.html
www.ndt.net/article/ct2003/v22/v22.html