Validation of kVp measurement using the HVL approach for standard beam qualities for mammography

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Abstract. In mammography imaging, the most common target material used in mammography machines are Molybdenum (Mo) target with Mo filters. In the publication of International Electrotechnical Commission (IEC) 61267, the establishment of mammography beam qualities assembly are given in 3 fixed parameters namely the target material which is Mo, the Mo filter thickness and the tube voltage. While, Mo target with rhodium (Rh) filters combination standard beam qualities were established by the Physikalisch-Technische Bundesanstalt (PTB) primary standard Laboratory. The objective of this study is to measure the kVp and HVL ranging from 23-31 kV. Later compare the displayed kilovoltage peak (kVp) on the control panel with the kVp measured using a non-invasive kVp meter and validating them with the HVL measurement. From the results, the kVp dialed and kVp measured shows significant difference by 2-4 kV. The HVL measured for the kVp before and after corrected also shows similar pattern, where the HVL after kVp is correct is almost identical to the standard beam qualities with the difference of 1%. This verifies that the kVp measurement using a non-invasive kVp meter can be validated with just a simple measurement of its HVL for mammography standard beam qualities.

1. Introduction

In mammography imaging, the most common target material used in mammography machine is Molybdenum (Mo) target since Mo are able to produce characteristic x-ray peaks at 17.5 keV and 19.6 keV for Mo target. In addition, x-rays attenuation filters such as Mo and Rh filters are also added to remove the unwanted low and high energy x-rays in the bremsstrahlung spectrum which proven to be an important role in the shaping of the mammography spectrum and useful for breast imaging. [1]

Common combination target and filter material for mammography x-ray are Mo target with 0.03mm thick Mo filters (Mo/Mo), and 0.025mm thick Rh filters with a Rh target (Rh/Rh). However, nowadays 0.025mm thick Rh filters with a Mo target (Rh/Mo) are also found in newer mammography machine such as the full field digital mammography (FFD) for imaging thicker and denser breast. [1] Other combination target filters available are tungsten (W) target with Aluminum (Al) and silver (Ag) filters [2]. These different target/filter materials will affect greatly on the calibration coefficient for semiconductor dosimeters as reported by Michiharu et al. [2]

The beam quality of mammography is often described in Half Value Layer (HVL). HVL in general is the thickness of material required to reduce one half the x-ray beam of its initial values [3]. The HVL can be determine experimentally or by computational models, which were demonstrated by Suk et al, in their study where they compared the results of HVL measured with HVL estimation of IPEM-78 (semi-empirical model) and SpekCalc (deterministic model) [3].
The standard mammography beam quality described by the International Electrotechnical Commission, in the publication of IEC 61267 [4], it provided us with 3 fixed parameters for establishment of mammography beam qualities assembly, which consist of the target of Molybdenum (Mo), 0.032mm ±0.002mm thickness of Mo filters and the tube voltage. Therefore, the HVL values are fixed at a specific radiation energy. In other words, the HVL relates with the energy of radiation [5]. In addition, for mammography clinical usage, ACR accreditation also provided guidelines recommended minimum HVL with compression paddle and maximum HVL based on the target/filter combination [1].

For mammography standard beams qualities, the HVL of Mo target with 0.03 mm Mo thickness filter combination was published in IEC 61267 and established by International Atomic Energy Agency (IAEA) standard laboratory. In the standards the tube voltage was fixed at 25kV, 28kV and 30kV with HVL for IEC standard beams are 0.28 mmAl, 0.31 mmAl and 0.33 mmAl at the respective voltage, while HVL for IAEA standard beams are 0.28 mmAl, 0.332 mmAl and 0.352 mmAl at the respective voltage. Meanwhile for 0.025 mm Rh thickness filter with Mo target combination the standard beam qualities were established by the Physikalisch-Technische Bundesanstalt (PTB) primary standard laboratory, where the tube voltage was also fixed at 25kV, 28kV and 30kV with HVL 0.34 mmAl, 0.38 mmAl and 0.39 mmAl respectively.

In this study, we compared the recorded kilovoltage peak (kVp) on the control panel versus kVp measured Non-invasive kVp meter and validate the kVp measurement using Half Value Layer (HVL) approach.

2. Materials and Methods
A highly stabilized industrial x-ray GE ISOVOLT Titan E with x-ray tube Molybdenum (Mo) target was used. Mo filter of 99.9% purity of 0.03mm thickness was used to obtain the standard IEC 61267 and IAEA beam quality the beam quality. A non-invasive solid state kVp Detector (RTI Piranha 657) was used to measure the output kVp of the x-ray tube. The detector was place 1 meter from the focus spot as shown in figure 1. The dialed kV ranged 23-31 kV was measured 3 time. Both of the displayed kVp on the control panel and the kVp measured was recorded.

![Figure 1](image.png)

The schematic diagram of the measurement set-up for kV measurement using a non-ionizing kVp meter and HVL measurement

The HVL measurement was done experimentally using a PTW ion chamber dosimeter (traceable to IAEA Standard laboratory). The chamber was placed 1 meter from the focal spot. The half value layer was measured using aluminium of 99.99% purity as the absorber and the data was plotted using Microsoft excel to determine the HVL. The kVp and HVL were measured from 23 to 31 kVp as shown in Table1.
Using the same set-up and tube Mo target, the Mo filter was changed to rhodium (Rh) filter of 0.025mm thickness with 99.9% purity in order to obtain the standard PTB beam quality for Mo/Rh target filter combination. The kVp and HVL were measured from 23 to 31 kVp.

3. Results and Discussion
The results show that the kV measurement of Mo/Mo target filter combination and the dialed kVp range 23kVp -31kVp have approximately 2-4 kVp of increment difference between recorded kVp on the control panel of the x-ray machine and the kVp measured by the non-invasive kVp meter as shown as in Table 1.

Table 1. The measured kVp using Pirahna non-invasive kVp meter

| kVp Dailed (kV) | kVp measured (kV) |
|----------------|-------------------|
| 23             | 25.44±0.02        |
| 25             | 27.72±0.02        |
| 27             | 30.05±0.05        |
| 29             | 32.40±0.02        |
| 31             | 34.74±0.02        |

Figure 2. The HVL of Mo target with 30µm Mo Filter before and after the kVp is corrected

Figure 3. The HVL of Mo target with 25µm Rh Filter before and after the kVp is corrected
Whereas, from the result of HVL measurement for Mo/Mo target filter combination, it shows that the HVL of the dialled kV before corrected was slightly higher compared to HVL of the standard beam from the standards laboratories with the maximum difference of 3%. However, after the kV was corrected to the kV measured, the results of HVL show almost similar to the standard beam from the standards laboratories with the maximum difference of 1% from IAEA laboratory as shown in figure 2. Both HVL measured before and after kVp corrected is still within the ACR clinical limits.

From the HVL measurement results of Mo target with 25µm Rh Filter as shown in figure 3, it also shows similar pattern with the HVL results for Mo/Mo target filter combination. After the kV is corrected the HVL measurement was almost the equivalent to the PTB standard lab HVL values with maximum of 1% difference. Nevertheless, HVL measured before and after kVp corrected appears to be in between the ACR clinical limits and PTB standard beam qualities.

The HVL results for both target filter combinations are consistent with the kVp measured using the non-invasive kVp meter. It clearly shows that before the x-ray voltage was corrected, the HVL value measured was significantly higher than the standard beam qualities suggested by the standard laboratories. After the kVp was corrected, the HVL value reduces and was almost identical with the standard beam qualities. This verifies that the displayed kVp value on the control panel is lower than the actual x-ray voltage output. Since the HVL measurement is very dependent on x-ray tube voltage by decreasing x-ray voltage output will also decrease HVL values.

4. Conclusions
From the results, we conclude that a simple measurement of HVL are able to validate the kVp measurement of x-ray voltage output using non-invasive kVp meter of standard mammography beam qualities. The Beam established in Nuclear Malaysia Standard Mammography laboratory using industrial x-ray system also complies with the ACR guidelines for mammography for clinical use and almost the similar to IAEA and PTB standard beam qualities for mammography.

5. References
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Acknowledgement
The authors would like to acknowledge the financial support from Universiti Sains Malaysia under FRGS/1/2018/STG02/USM/03/3/6711631 and extend our acknowledgement to Nuklear Malaysia for providing materials and equipment for this project.