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Effect of collimator scatter factors on dose calculation of different breast cancer cases in radiotherapy

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***Keywords:** Collimator scatter factor, mini-phantom, build-up cap, brass, MLC transmission.*

ABSTRACT

Background: The present study aims to estimate the effect of collimator, phantom and Multi-Leaf Collimator (MLC) scatters on dose calculation in different breast cancer cases using acrylic, brass build-up caps and acrylic mini-phantom in the measurements. ***Materials and Methods***: Collimator scatter factors (Sc), phantom scatter factors (Sp) and MLC transmission factors for different field sizes ranging from 1 × 1 cm^2 to 40 × 40 cm^2 for energies 6 MV and 15 MV were measured using acrylic mini-phantom (PTW and local mini-phantom), acrylic build up cap and brass build up cap where the farmer ionization chamber was used as detector in this study and semiflex detector was used but only with small field sizes from 1 × 1 cm^2 to 4 × 4 cm^2 and scatter effect on the dose calculation in different breast cancer cases was evaluated. ***Results***: The results in this study show that there is no significant difference between MLC transmission factors using acrylic mini-phantom and brass build-up cap with energy 6 MV where the transmission factor value is 0.007 and 0.0071 with acrylic mini-phantom and brass build- up cap, respectively. Also it is clear that brass build-up cap gives the highest collimator scatter factors results where collimator scatter factors start at value 0.963 at field size 4 × 4 cm^2 then increase gradually to end at point value 1.049 at field size 40 × 40 cm^2. In breast cancer cases, there is sharp increase in organ at risk doses with brass build-up cap. ***Conclusion***: From this study it is evident that almost there is large variation between the acrylic build-up cap, acrylic mini-phantom and brass build-up cap where brass build-up achieve higher results in most measurements.

INTRODUCTION

Modern medical linear accelerators can be operated in two modes; electrons or photons for cancer treatment. When photons are used in the treatment, contaminants may be created through a photonuclear reaction from hardware components in the head of the linear accelerator such as the collimators, filters and target. Optimal tumour control with limited side effects requires delivering the maximum prescription dose to the Gross Tumor Volume (GTV) while simultaneously reducing the dose to the surrounding structures. To account for target movement, a Clinical Target Volume (CTV) is created by adding a margin around the GTV. Planning Target Volume (PTV) take into consideration the systematic uncertainties with margin around CTV (1).

The quality of radiation therapy delivery has a direct impact on the dose delivered to the patient. This takes into account dosimetric guidelines as they influence the clinical outcome. Treatment verification aims to measure and ensure the accuracy of the radiation that produce during treatment and the fluence of dose distribution. These dose verification checks are acquired through the delivery of dose of actual patient treatment to phantoms. Heterogeneous and homogeneous phantoms coupled with ion chambers have been employed to monitor dose delivery for multi-field plans (2).

The absorbed dose at the point within a phantom can be divided into two components: a part due to primary radiation and a second part carried by photons scattered (3).

In dosimetry systems, the measurement of the total scatter factor in a phantom (Shp) and the head-scatter factor (Sh) or phantom scatter factor is the major component of dosimetry. Air measurement with an ion chamber covered with a buildup cap was done (4-6).

The primary photon beam that produce in the head of linear accelerator is collimated to fit the size of the tumor resulting in the desired field size (7).

With Monte Carlo simulations, the minimum thickness of a mini-phantom to reach the lateral electron equilibrium can be estimated, as a function of the beam energy (with the TPR20, 10). The use of brass build-up caps was suggested for small field measurements (8).

The strong reduction in the thickness that made with the brass build-up caps is suitable for small field size with collimator scatter measurements. For large fields and high energies, the plastic build-up caps

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might be preferable (9).

To measure *Sc,* buildup cap must be covered by the field. So for high-energy beams, the large diameter buildup cap prohibit the measurement of *Sc* in small fields. In order to solve this size problem, cylindrical buildup caps have been constructed from materials that have higher density than water, such as aluminum, brass, and lead (10, 11) This dependence on buildup cap material becomes greater with higher energy beams (12, 13).

The accurate knowledge of the dosimetric features of the clinical beams and how these are incorporated and modelled in the configuration of the algorithm can play a important role and impact on the final dose calculation (14).

Multileaf Collimators (MLCs) are a well-accepted tool in radiotherapy were used to replace blocks for simple field shaping and later for conformal radiotherapy. With the advent of intensity Modulated RSadiotherapy (IMRT) based on computerized treatment plan optimization, a MLC is frequently considered to be a necessary for IMRT (15).

This study aims at the measurement of collimator scatter factors using acrylic mini-phantom (PTW and local mini-phantom), acrylic build up cap and brass build up cap at the same time where these different types of phantoms are the most common phantoms that use a separate in radiotherapy in all over the world in the measurement of collimator scatter, also in this study the effect of collimator scatter with the previous different phantoms on organ at risk doses in breast cancer cases is evaluated. Also, in this study the appropriate phantom in the collimator scatter measurement with different field sizes is recommended.

MATERIAL AND METHODS

Materials

Acrylic mini-phantom

Acrylic cylinder mini phantom (PTW dosimetry system, Germany) described in ESTRO, it was used with local acrylic mini phantom (homemade phantom). They are 188 mm in height and of 40 mm in diameter for each, the wall thicknesses cover the energy range from 60Co to 20 MV photons (16).

Acrylic build-up cap

A crylic build-up caps (PTW dosimetry system, Germany) were used with thimble ionization chambers for in-air measurements in photon beams when electron equilibrium is desired. Optionally, a variety of build-up caps is available for different ionization chamber types and for different photon energy ranges. Its density of 1.185 g/cm^3 with wall thickness 11.91 mm. Acrylic build up cap, due to their size, it may be disadvantageous when used in small beams.

Brass build-up cap phantom

The brass build-up cap phantoms (PTW dosimetry system, Germany) are designed for "in air" measurements for small fields with an axial irradiation. Its density of 8.515 g/cm^3 with wall thickness 2.71 mm. Due to a minimum wall thickness they can be used for field sizes down to 1.5 cm.

Siemens Oncor linac treatment machine

It is a multi-energy machine (6 MV and 15 MV operating up to 500 MU/min and 6 electron energies) of Oncor model (Siemens company, Germany). The Multi Leaf Collimator (MLC) delivery system replaces the lower movable jaws inside the linear accelerator head. The MLC for the ONCOR linear accelerator has 41 pairs of inner leaves with a 1.0 cm width that is projected at isocenter. This machine has 3D Conformal and static IMRT (step and shot) facilities.

Xio treatment planning system

XIO Treatment Planning (ELEKTA CMS, England, version 4.6.3) employs convolution, Clarkson and superposition algorisms in dose calculation for photon mode therapy and pencil beam algorithm in electron mode therapy. It has different features with advanced facility that use in treatment of patient in radiotherapy as an Intensity Modulated Radiotherapy (IMRT) option that uses static method in treatment planning using inverse planning software.

Methods

The collimator scatter factors were measured using acrylic mini-phantom (PTW and local mini-phantom) for different field sizes from 1 × 1 cm^2 to 40 × 40 cm^2, semiflex and farmer ionization chamber were used as detector in the measurements (semiflex chamber was used with small field sizes from 1 × 1 cm^2 to 4 × 4 cm^2 and farmer chamber was used with field sizes from 5 × 5 cm^2 to 40 × 40 cm^2), for energies 6 MV, 15 MV and the mini-phantom was inserted parallel to the beam central axis on the treatment couch of the treatment machine of type siemens oncor impression and the laser was adjusted on center of the sensitive volume of ionization chamber that inserted inside the mini-phantom. The field size 10 ×10 cm^2 was used as reference field size with field sizes from 5 ×5 cm^2 to field size 40 × 40 cm^2 and field size 4 × 4 cm^2 used as reference field size with field sizes from 1 × 1 cm^2 to 4 × 4 cm^2 to calculate the collimator scatter factor. The same previous steps were repeated with acrylic build-up cap and brass build-up cap. This is addition to MLC transmission and collimator transmission measurements using the previous mini-phantom and build-up cap in the measurements were performed, in MLC transmission measurements, the collimator was opened and MLC was completely closed and the phantom with ion chamber was adjusted at center of leaf bank, on the other hand, in collimator transmission measurement,

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the previous steps were repeated but the MLC was completely closed and collimator was opened the phantom with ion chamber was adjusted at center of collimator. All the previous measurements were transferred to xio treatment planning system to design different treatment machines with energies 6 MV and 15 MV using the different measured scatter factors. These different machines were used in the dose calculation in different breast cancer to evaluate the effect of measured scatter factor on the doses reach to organ at risks as lung, heart and spinal cord.

Statistical data analysis

The data analyzed by estimation of p-value that indicated the significant and non-significant difference between the data using excel sheet with t-test as it was used in the calculation of p-value.

RESULTS

MLC and collimator transmission scatter factors

Figure 1 (a, b) shows the MLC transmission scatter factors using acrylic mini-phantom, acrylic buildup cap and brass build-up cap as scattering medium and PTW farmer ionization chamber as detector in measurement of transmission scatter factor for energies 6 MV and 15 MV on Siemens Oncor impression treatment machine.

From figure 1 it was found that there is no significant difference between MLC transmission factors using acrylic mini-phantom and brass build-up cap with energy 6 MV where the transmission factor value is 0.007 and 0.0071 with acrylic mini-phantom and brass build-up cap, respectively. This value of transmission factor drop to 0.0063 with acrylic build-up cap for the same energy. In the contrary with energy 15mv, there is sharp increase in MLC transmission factor with acrylic build -up cap that is 0.011 in comparison to mini-phantom and brass build-up cap that achieve similar results 0.007 and 0.0066, respectively.

Figure 2 (a, b) shows the collimator transmission scatter factors using acrylic mini-phantom, acrylic buildup cap and brass build-up cap as scattering medium and PTW ionization chamber as detector in measurement of collimator scatter factor for energies 6 MV and 15 MV on siemens oncor I mpression treatment machine.

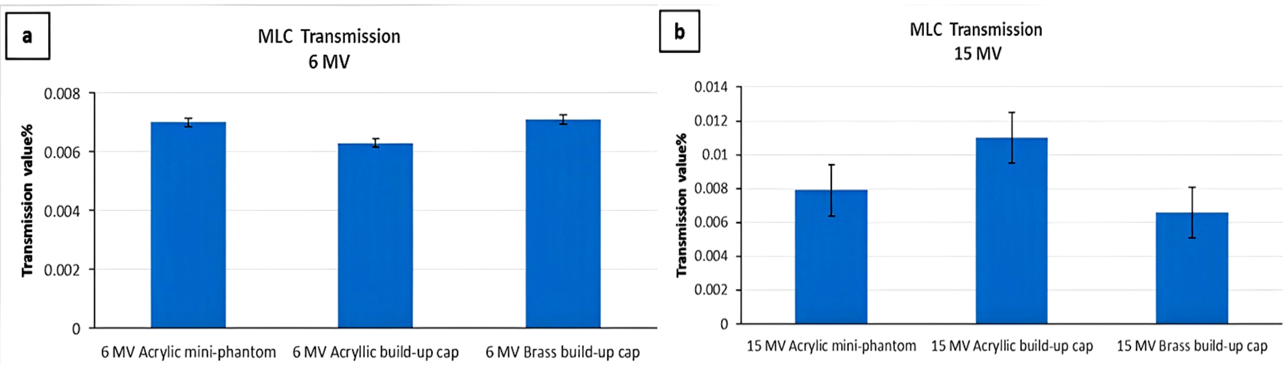

Figure 1. The variation of MLC transmission factors for energies **(a)** 6 MV and **(b)** 15 MV with SD in the measurements using Acrylic mini-phantom, Acrylic build-up cap and Brass build-up cap.

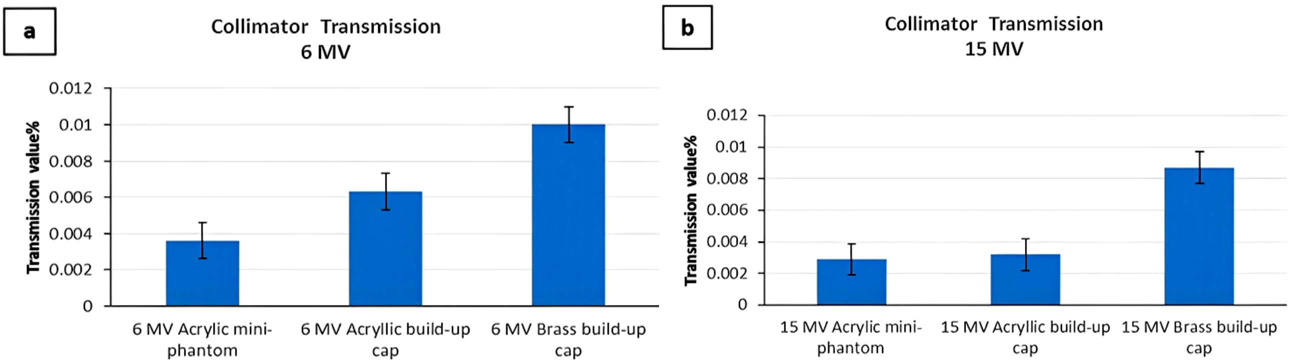

Figure 2. The variation of Collimator Transmission factors for energies **(a)** 6 MV and **(b)** 15 MV with SD in the measurements using Acrylic mini-phantom, Acrylic build-up cap and Brass build-up cap.

From figure 2 it was clear that the transmission values for acrylic mini-phantom, acrylic build-up cap and brass build-up cap are 0.0029, 0.0032 and 0.0087, respectively where brass build-up cap achieve the most increase in collimator transmission scatter factors that agree with MLC transmission factor with respect to high density brass build-up cap. The brass build-up cap shows the same behavior with energy 15 MV where it achieve more increase collimator transmission factor that is 0.0087.

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Collimator scatter factors

a. Collimator scatter factors with field sizes from 4 ×4 cm² to 40 × 40 cm²

Figure 3 shows the variation in collimator scatter factors for energies 6 MV with acrylic mini-phantom, acrylic build-up cap and brass build-up cap for different field sizes from 4 ×4 cm² to 40 × 40 cm² using PTW farmer ionization chamber detector in the measurement.

From figure 3, the results show that the collimator scatter factors with brass build-up cap give the highest results where collimator scatter factors start at value 0.963 at field size 4 × 4 cm² then increase gradually to end at point dose of value 1.049 at field size 40 × 40 cm². On the other hand, the acrylic build-up cap has the lowest collimator scatter factor that start at point 0.95 and reach finally to point dose of value 1.035 at the largest field size while the acrylic mini-phantom represent mid values results between acrylic build-up cap and brass build-up cap that start at 0.96 and reach to 1.039 at field size 40 × 40 cm², acrylic build-up cap, acrylic mini-phantom and brass build-up cap collimator scatter factors meet at field size 10 × 10 cm².

From figure 4, it was found that the brass build-up cap at energy 15 MV achieve the highest result at small field size from 4 × 4 cm² to 8 × 8 cm² but this behavior is reversed at large field size from 10 × 10 cm² to 40 × 40 cm² that is similar to acrylic mini-phantom results with these large field sizes but at small field sizes 4 × 4 cm² to 8 × 8 cm², acrylic build-up results are mid-way between brass build-up cap (higher collimator scatter factors) and acrylic mini-phantom (lower collimator scatter factors).

b. Collimator scatter factors with small field sizes from 1 × 1 cm² to 3 × 3 cm²

Figure 5 shows the variation in collimator scatter factors for energies 6 MV and 15 MV with acrylic mini-phantom, acrylic build-up cap and brass build-up cap for different field sizes from 1 × 1 cm² to 3 × 3 cm² using PTW semiflex ionization chamber detector in the measurement.

From figures 5, 6 and 7 it is clear that there is sharp increase in collimator scatter factors with brass build up cap in comparison to acrylic mini-phantom and acrylic build-up cap that show similar collimator scatter factors.

Phantom scatter factors

Figure 8 shows the variation in phantom scatter factors with different field sizes at beam energy 6 MV using acrylic mini-phantom, build-up cap and brass build-up cap with farmer ionization chamber detector in the measurements.

In this figure, at field sizes from 10 × 10 cm² to 40 × 40 cm² the acrylic mini-phantom, build-up cap and brass build-up cap, nearly they have the same behavior with phantom scatter factors. On the other hand, at small field sizes 4 × 4 cm² and 5 ×5 cm², the acrylic build cap and brass build-up cap show slight increase in phantom scatter factors in comparison to acrylic mini-phantom.

Figure 9 shows the variation in phantom scatter factors with different field sizes at beam energy 15 MV using acrylic mini-phantom, build-up cap and brass build-up cap with farmer ionization chamber detector in the measurements.

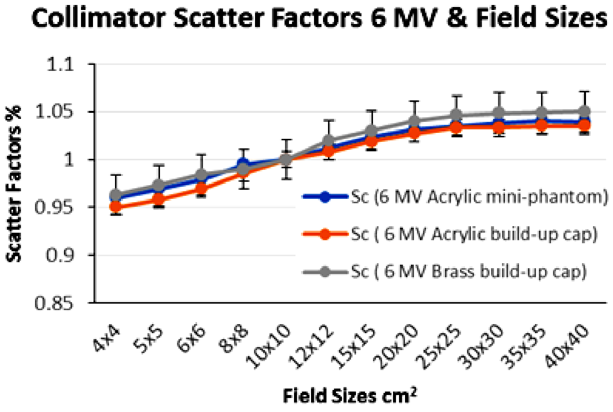

Figure 3. The variation of Collimator Scatter Factors for energy 6 MV with SD in the measurements at different field sizes from 4 × 4 cm² to 40 × 40 cm² with Acrylic mini-phantom, Acrylic build-up cap and Brass build-up cap.

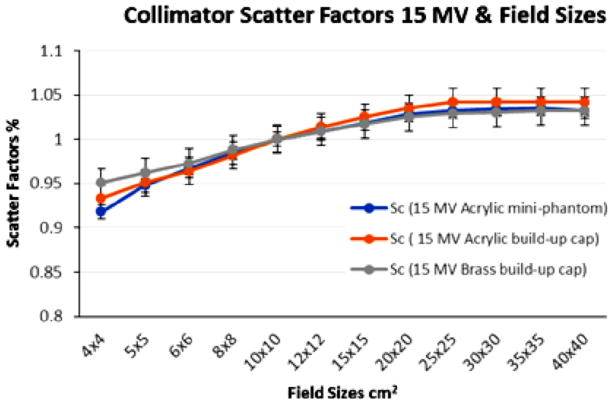

Figure 4. The variation of collimator scatter factors for energy 15 MV with SD in the measurements at different field sizes from 4 × 4 cm² to 40 × 40 cm² with Acrylic mini-phantom, Acrylic build-up cap and Brass build-up cap.

In this figure, on the contrary the results in figure 8, at small field sizes 4 × 4 cm² and 5 × 5 cm², acrylic build-up cap, mini-phantom and brass build cap, approximately, they have the same behavior with phantom scatter factors but, at field sizes from 10 × 10 cm² to 40 × 40 cm², acrylic build-up cap show lower phantom scatter factors in comparison to brass build-up cap and acrylic mini-phantom that have the same behavior with phantom scatter factors.

Effect of scatter factors on breast cancer cases

Figure 10 shows mean dose for V20% of lung in 50 breast cancer cases using different machines design that created on XIO TPS that included different scatter factors (collimator and phantom scatter factors) that was measured with acrylic mini phantom(local and PTW), acrylic build-up cap and brass build-up cap phantoms with farmer ionization chamber detector, the PTW acrylic mini phantom represents the reference mini phantom that used in measurements of scatter factors during beam data commissioning and data was transferred to the treatment planning system before the treatment of patient on linac.

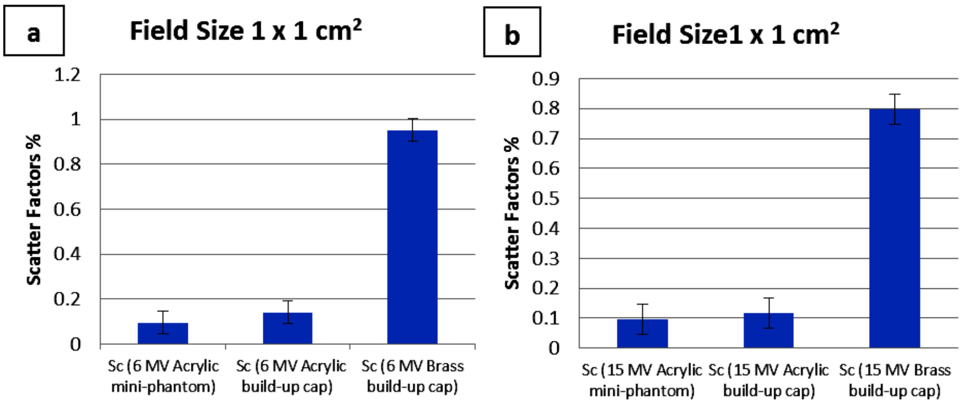

Figure 5. The variation of Collimator Scatters factors for energies **(a)** 6 MV and **(b)** 15 MV for field size 1 × 1 cm^2 using Acrylic mini-phantom, Acrylic build-up cap and Brass build-up cap.

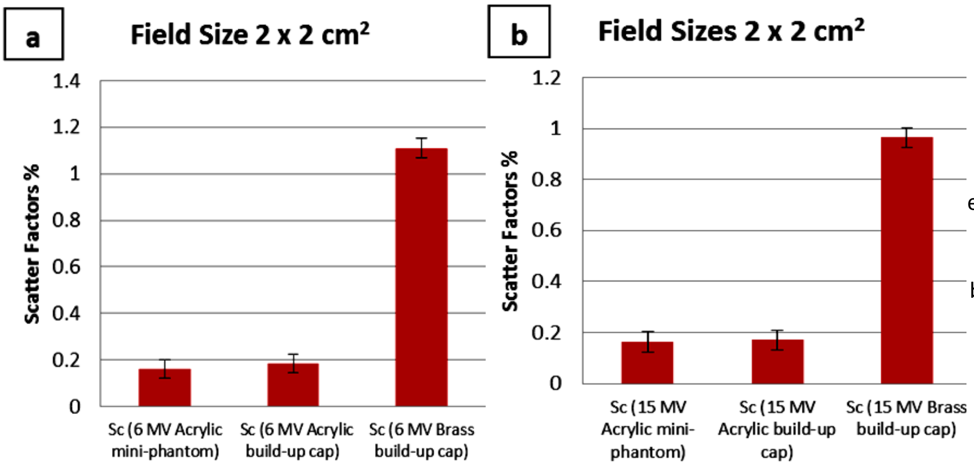

Figure 6. The variation of Collimator Scatters factors for energies **(a)** 6 MV and **(b)** 15 MV for field size 2 × 2 cm^2 using Acrylic mini-phantom, Acrylic build-up cap and Brass build-up cap.

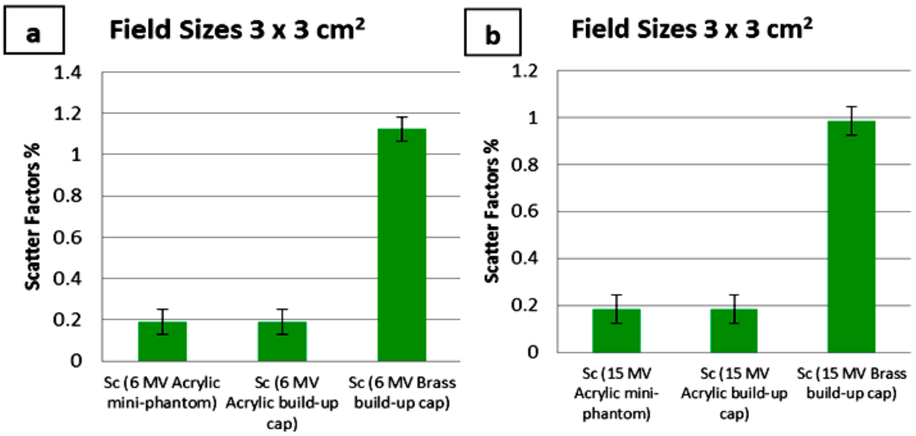

Figure 7. The variation of Collimator Scatters factors for energies **(a)** 6 MV and **(b)** 15 MV with SD in the measurements for field size 3 × 3 cm^2 using Acrylic mini-phantom, Acrylic build-up cap and Brass build-up cap.

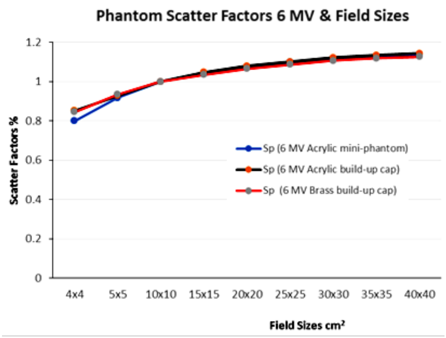

Figure 8. The variation of Phantom Scatter Factors for energy 6 MV at different field sizes from 4 × 4 cm^2 to 40 × 40 cm^2 with Acrylic mini-phantom, Acrylic build-up cap and Brass build-up cap.

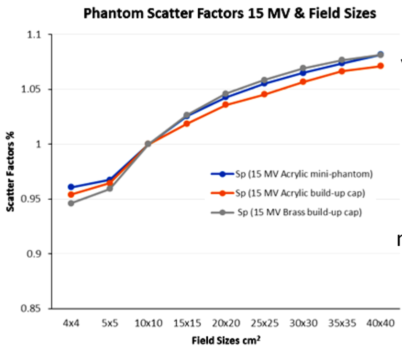

Figure 9. The variation of Phantom Scatter Factors for energy 15 MV at different field sizes from 4 × 4 cm^2 to 40 × 40 cm^2 with Acrylic mini-phantom, Acrylic build-up cap and Brass build-up cap.

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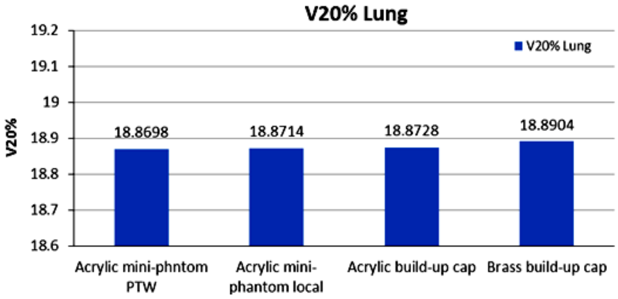

Figure 10. The variation of mean V20% of lung in different breast cancer cases with Acrylic mini-phantom, Acrylic build-up cap and Brass build-up cap.

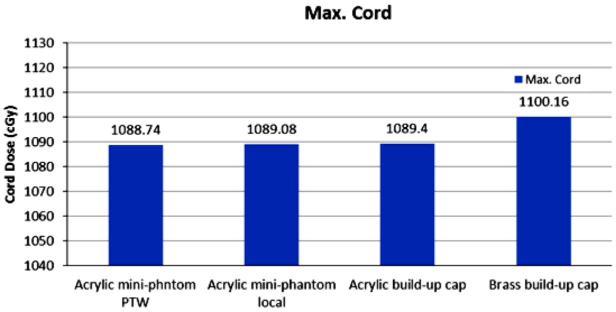

Figure 12. The variation of max. Spinal cord dose in different breast cancer cases with Acrylic mini-phantom, Acrylic build-up cap and Brass build-up cap.

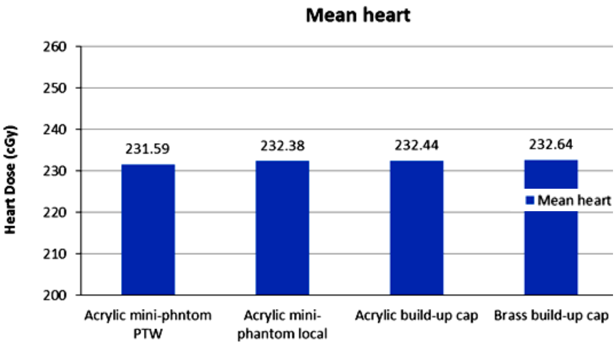

Figure 11. The variation of mean heart dose in different breast cancer cases with Acrylic mini-phantom, Acrylic build-up cap and Brass build-up cap.

From this figure, it was found that there is similar V20% lung dose with acrylic mini-phantom (local and PTW) and acrylic build-up cap while the V20% with brass build-up shows slight increase in V20%.

Similar behavior is shown in figures 11 with the mean heart dose but figure 12 that included maximum Spinal cord dose with acrylic (mini phantom and buid-up cap) and brass build-up cap shows more increase with maximum spinal cord dose with brass build-up cap in comparison to acrylic mini phantom and build-up cap.

DISCUSSION

The head scatter factor plays major a role in output measurements of megavoltage radiation beams as well as in beam modelling of treatment planning systems which are used for advanced treatment delivery techniques with summation of series of MLC shaped fields (17, 18).

The increase in Sh with field size may be attributed to the radiation scattered from the primary collimator and flattening filter in the treatment head when the collimator size increase. Also increasing the jaw opening decreases the number of photons back scattered from the jaw to the monitor chamber by a small amount (19).

The variation in results with acrylic mini-phantom and brass build-up cap at energy 6 MV can be explained by that the large volume of acrylic mini-phantom and high density for brass build-up cap that lead to more scattering in comparison to acrylic build-up cap, where cylindrical build-up caps constructed of high Z material have been reported to give results that differ significantly from those of low Z (20, 21), hence more transmission scatter factors. In the contrary with energy 15mv, there is sharp increase in MLC transmission factor with acrylic build-up cap that is 0.011 in comparison to mini-phantom and brass build-up cap that achieve similar results 0.007 and 0.0066, respectively as shown in figure 1. From overall results in this figure, it is clear that there is increase in MLC transmission factors with 15 MV in comparison to 6 MV as the beam energy increases, the contamination of electrons have higher energy and become more penetrating, hence more scattering results (22). there is gradually increase in collimator transmission scatter factors with energy 6 MV from acrylic mini-phantom and acrylic build-up cap to brass build-up cap as shown in figure 2. From overall results in this figure, it was found that there are increase in scatter factors results with collimator transmission factors at energy 15 MV similar to MLC transmission factors results[16].

There is significant difference between mini-phantom and brass build-up cap ($p<0.05$) and in significant difference between mini-phantom and acrylic build-up ($p>0.05$). Figure 4 shows the variation in collimator scatter factors for energy 15 mv with acrylic mini-phantom, acrylic build-up cap and brass build-up cap for different field sizes from 4×4 cm^2 to 40×40 cm^2 using PTW farmer ionization chamber detector in the measurement.

There is significant difference between mini-phantom and acrylic build-up cap ($p<0.05$) and in significant difference between mini-phantom and brass build-up ($p >0.05$) in the contrary to the results with energy 6mv Where it was observed in figures 3 and 4.

From figures 5, 6 and 7 it is clear that there is sharp increase in collimator scatter factors with brass build up cap in comparison to acrylic mini-phantom and acrylic build-up cap that show similar collimator scatter factors, this behavior of brass build -up cap can explained by the high density (8.7 gm/cm^3) and small volume of brass build-up cap in comparison to acrylic build-up cap and mini-

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phantom that have larger volume and lower density (1.18 gm/cm^3) than brass build-cap hence the brass build-up cap achieve more field coverage with small field size that cause more scattering factors with brass build-up cap.

There was significant difference between acrylic build cap and brass build-up cap ($p<0.05$) and in significant difference between acrylic mini-phantom and brass ($p>0.05$) as shown in figure 8.

There was significant difference between acrylic build cap and brass build-up cap ($p<0.05$) and in significant difference between acrylic mini-phantom and brass ($p>0.05$) as shown in figure 9.

there was similar V20% lung dose with acrylic mini-phantom (local and PTW) and acrylic build-up cap while the V20% with brass build-up shows slight increase in V20% as shown in figure 10.

Where ($p>0.05$) shows insignificant difference between acrylic mini-phantom and build- up cap. On the contrary, p-value with brass build-up cap ($p<0.05$) shows significant difference between brass build-up cap and acrylic mini-phantom and build-up cap in different breast cancer cases as shown in figure 11.

This study is the first study that estimate the effect of collimator scatter, phantom scatters, collimator and MLC transmission on dose calculation in breast cancer sing the different types of phantoms in the same study and the estimation of impact of these scatter factors on doses reach the organ at risk. Berris *et al.* (23) study was utilized Monte Carlo simulation methods for the assessment of radiation doses imparted to all organs at risk to develop secondary radiation induced cancer, for patients undergoing radiotherapy for breast cancer but not consider these scatter factors, Zurl *et al.* (24) study was estimated the risk factor from doses reach the contra lateral breast in young women patient with different mode of breathing but it wasn't evaluated these the scatter factors.

CONCLUSION

From this study it is evident that almost, there is large variation in different types of scatter factors results with acrylic build up cap, acrylic mini-phantom and brass build up cap according to the volume of phantom and the density of phantom material that used in the measurement where brass build up achieve higher results in most measurements, the variation in the scatter results impact on organ at risk doses in different breast cancer cases especially with brass build up cap, although these variations in scatter factors with different types of phantom but the effect of these variations on dose calculation is not clinical significant on organ at risk doses so it is recommended to use acrylic mini-phantom or acrylic build up cap or brass build up cab in the measurement according to the type of phantom available in the hospital. On the contrary with small field sizes, it is preferable to use brass build-up cap in the measurement that achieve more field coverage for the phantom and high accuracy measurements.

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Ethical consideration: The author ensure ethical publication practices involving transparency and integrity in the publication of manuscript.

Author contribution: M.A.E: The experimental measurements and data analysis, A.M.A: Data analysis and manuscript writing, H.S.M. and S.T: Manuscript revision.

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