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Dosimetric effects of brass mesh bolus on skin dose and dose at depth for postmastectomy chest wall irradiation

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Abstract

Purpose: To investigate the feasibility of using the brass mesh bolus as an alternative to tissue-equivalent bolus for post mastectomy chest wall cancer by characterizing the dosimetric effects of the 2-mm fine brass bolus on both the skin dose, the dose at depth and spatial distribution.

Materials and methods: Surface dose and percent depth dose data were acquired for a 6 MV photon beam in a solid water phantom using MO*Skin*™ Gafchromic EBT3 film and an Advanced Markus ionization chamber. Data were acquired for the case of: no bolus, Face-up bass bolus, Face-down brass bolus, double brass bolus, 0.5 cm and 1.0 cm of Superflab TE bolus. The exit doses were also measured via MO*Skin*™ dosimeter and Markus ionization chamber. Gafchromic EBT3 film strips were used to plot dose profile at surface and 10 cm depth for Face-up brass, Face-down brass, double brass, 0.5 cm and 1.0 cm of Superflab TE bolus.

Results: The surface dose measured via MOSkin™ dosimeter increased from 19.2 ± 1.0% to 63.1 ± 2.1% under Face-up brass discs, 51.2 ± 1.2% under Face-up brass spaces, 61.5 ± 0.5% under Face-down brass discs, and 41.3 ± 2.1% under Face-down brass spaces. The percentage difference in the dose measured under brass discs between Face-up versus Face-down was less than 2% for entrance dose and 10% for exit dose, whereas the percentage difference under brass spaces was approximately 3% for entrance dose and about 5% for the exit dose. Gafchromic EBT3 film strip measurements show that the mesh bolus produced ripple beam profiles due to the mesh brass construction.

Conclusions: Brass bolus does not significantly change dose at depth (less than 0.5%), and the surface dose is increased similar to TE bolus. Considering this, brass mesh may be used as a substitute for TE bolus to increase superficial dose for chest wall tangent plans.

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Purpose: To investigate the feasibility of using the brass mesh bolus as an alternative to tissue-equivalent bolus for post mastectomy chest wall cancer by characterizing the dosimetric effects of the 2-mm fine brass bolus on both the skin dose, the dose at depth and spatial distribution.

Materials and methods: Surface dose and percent depth dose data were acquired for a 6 MV photon beam in a solid water phantom using MO*Skin*™, Gafchromic EBT3 film and an Advanced Markus ionization chamber. Data were acquired for the case of: no bolus, Face-up bass bolus, Face-down brass bolus, double brass bolus, 0.5 cm and 1.0 cm of Superflab TE bolus. The exit doses were also measured via MO*Skin*™ dosimeter and Markus ionization chamber. Gafchromic EBT3 film strips were used to plot dose profile at surface and 10cm depth for Face-up brass, Face-down brass, double brass, 0.5 cm and 1.0 cm of Superflab TE bolus.

Results: The surface dose measured via MO*Skin*™ dosimeter increased from 19.2 ± 1.0 % to 63.1± 2.1 % under Face-up brass discs, 51.2 ± 1.2 % under Face-up brass spaces, 61.5 ± 0.5 % under Face-down brass discs, and 41.3 ± 2.1 % under Face-down brass spaces. The percentage difference in the dose measured under brass discs between Face-up versus Face-down was less than 2 % for entrance dose and 10 % for exit dose, whereas the percentage difference under brass spaces was approximately 3 % for entrance dose and about 5 % for the exit dose. Gafchromic EBT3 film strip measurements show that the mesh bolus produced ripple beam profiles due to the mesh brass construction.

Conclusions: Brass bolus does not significantly change dose at depth (less than 0.5 %), and the surface dose is increased similar to TE bolus. Considering this, brass mesh may be used as a substitute for TE bolus to increase superficial dose for chest wall tangent plans.

Key words: brass mesh bolus, MO*Skin*™*, in vivo* skin dosimetry.

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1. Introduction

Post-mastectomy radiotherapy (PMRT) has been proven to increase the locoregional and the overall survival of patients with high-risk breast cancer [1-3]. The chest wall is the most frequent site of recurrence and delivering adequate radiation doses to the chest wall is crucial to reducing the risk of treatment failure [4]. The chest wall is a challenge to treat with radiation therapy due to its irregular surface contours, large curvature and near-surface target volume [5].

The most widely used treatment modality for patients with chest wall breast cancer is megavoltage photon external-beam radiotherapy, particularly utilizing the tangential beam arrangement. Megavoltage photons are usually used for their depth penetration properties whilst providing for skin sparing effects. For 6-MV photons, the depth of maximum dose (d_{max}) is 1.5 cm, with the surface dose substantially lower. For opposed tangential fields, the skin receives approximately 80 % of dose prescription due to this sparing effect [6]. Thus, the skin sparing effect of the MV beam is not desired in the case of the chest wall, where the target extends to the skin, based on the definition of the Radiation Therapy Oncology Group (RTOG) for the chest-wall target volume [7].

Tissue-equivalent material bolus is commonly used during post-mastectomy radiotherapy to provide an adequate dose build-up in the skin and superficial chest wall [5, 8]. Commercially available tissue-substitute materials are Superflab and Vaseline based boluses. Previous studies have shown a few limitations of using these types of boluses. One of these is the lack of conformity to the chest wall due to its thickness, rigidly and inflexibility, which will reduce the efficiency of the build-up material, as it has been shown that the surface dose may decrease by as much as 10 % for air gaps up to 10 mm [9]. Anderson *et al.*, 2004 reported that the effect of the air gap between the skin of the patient and the bolus may lead to harmful hot spot doses or underdosage [10].

A second issue with tissue-equivalent bolus has been identified by Ordonez-Sanz *et al*.[11]. They demonstrated is the difficulty in maintaining a uniform thickness across the bolus surface when Vaseline boluses are used. The bolus was shown to be very thin at the most anterior part of the breast, providing less build-up material, leading to less dose at the skin.

Another drawback of tissue-equivalent bolus is the requirement of two treatment plans (one for the bolus and the other plan for no bolus) due to the attenuation differences in the absence and presence of the bolus. The need for two treatment plans increases the workload for centers, which use the TE bolus.

An alternative to tissue-equivalent bolus that has been adopted by some institutions is brass mesh bolus. In 2008, the Radiation Oncology Department at the University of California, Davis (UCD) started using a fine brass mesh bolus (Whiting & Davis, Attleboro Falls, MA) when delivering post mastectomy radiotherapy (PMRT) as an alternative to tissue equivalent (TE) bolus [6].

The brass mesh bolus is constructed using a regular mesh of interlinked brass discs, where brass discs are interlocked together to form a mesh, as shown in Figure 1. It has thickness of 1.5 mm, a density of 8.73 g/cm^3 and a cross section of 45 × 45 cm^2 [12, 13].

Fig.1 Brass mesh bolus

Like a traditional TE-bolus, the brass bolus decreases the radiation buildup depth and thereby increases the radiation dose delivered to the skin. The strongest advantage of the brass bolus over tissue equivalent bolus, as previously reported [6, 11, 14], is the ability to conform to the irregular contours of the chest wall with fewer gaps, which is better than TE- bolus material. Furthermore, the local control for the surface skin reaction has been shown to improve to moderate erythema, when brass bolus used [15]. Healy *et al.* [6] investigated the clinical use of brass mesh as an alternative to TE- bolus for patients treated with postmastectomy chest wall

radiation therapy. They concluded that when brass mesh is used in the chest wall PMRT, the majority of patients (88 %) at the end of treatment achieved moderate erythema at cumulative radiation doses of approximately 5 Gy for the skin. Another benefit of using brass mesh bolus is the reduced impact on the dose at depth compared to tissue-equivalent bolus [11, 16]. The results from the study performed by UCD, during the commission of the clinical use of brass mesh, demonstrated that the brass mesh bolus did not influence the dose below d_{max} and that monitor unit (MUs) did not change significantly with its use. Consequently, the use of a brass mesh reduces the complexity of accounting for a bolus in simulation and treatment planning and as such only one treatment plan is required [6].

The goal of this research is to investigate the feasibility of using the brass mesh bolus as an alternative to tissue- equivalent (TE) bolus for post mastectomy chest wall cancer by preforming dosimetric characterizations of the 2-mm fine brass mesh bolus in particular, the effect of brass bolus on dose build-up at the surface (beam entry and exit), as well as beam profiles and percentage depth doses. What is unique in this study is that the measurements were performed with MO*Skin*™ dosimeter MO*Skin*™ dosimeter has compact size and extra resolution, thus achieving more accurate skin measurements under the fine structure of the brass spaces and discs. The different configurations compared in this work are: Face-up brass bolus, Face-down brass bolus, double brass bolusand TE-Superflab bolus, as shown in Figure 2. The construction of the mesh brass bolus is different from both side, as shown in Figure 2 a-b.

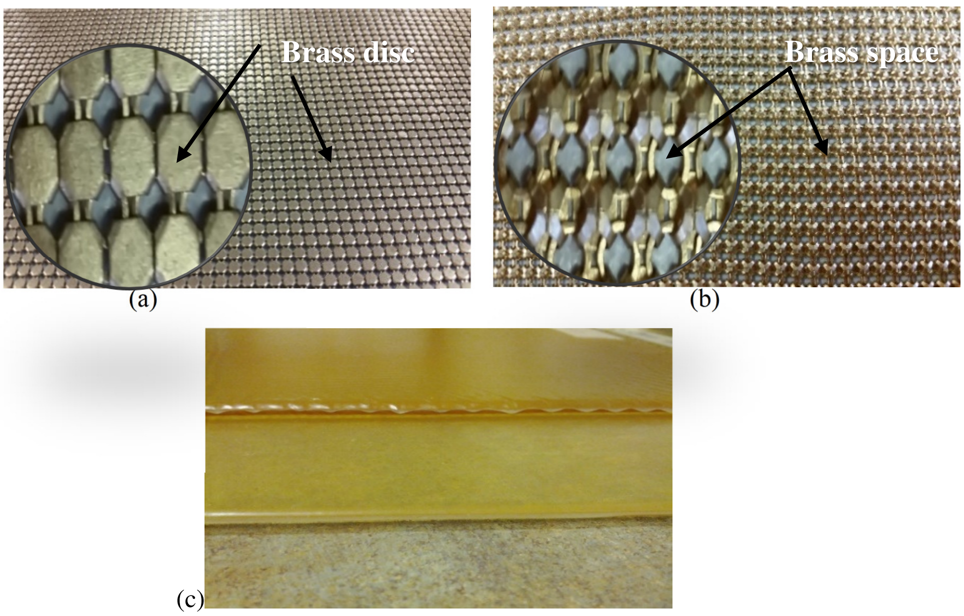


Fig.2 Bolus materials used in this study: (a) Face-up brass, (b) Face-down brass, (c) Superflab bolus.

2. Materials and Methods

2.A. Attenuation effect of brass mesh bolus

The effect of the attenuation of the brass mesh bolus on the dose deposition was evaluated using an advanced Markus parallel-plate ionization chamber 0.02 cm^3, Model 34045 (PTW Freiburg, Germany). The physical effective point of measurement for the Markus chamber is defined as 0.03 mm, at the inner surface of the proximal collecting plate. The plate separation is fixed at 1 mm; the guard ring is 2 mm and the external dimensions are 30 mm diameter × 14 mm. The Markus chamber was placed on the central axis of a 10 × 10 cm^2 field size 6MV photon beam, 100 SSD cm at a depth of 10cm in a solid water phantom. The PTW Unidos electrometer was used to operate the Markus chamber at a potential of +300V. The attenuation factor was determined as the ratio of measurements with and without the brass mesh on top of the phantom. The attenuation factor for one-layer and double layer of brass bolus as well as the TE- Superflab bolus were determined. The over response correction factor for the advanced Markus chamber, was calculated using the modified Velkley correction formula [17, 18].

2.B. Percentage depth dose (PDD) measurements.

The central axis (CAX) PDDs were measured using 3 × 3 cm^2 Gafchromic EBT-3 film pieces. Solid water blocks with an area of 30 × 30 cm^2 were used to provide the proper scattering conditions, with a slab 10 cm thick for the back-scattering material and multiple slabs to obtain the depth dose profile from 0 to 10 cm depth. The films were irradiated with 300 MU by 10 × 10 cm^2 field at 100 cm SSD by a 6 MV photon beam on a Varian Clinac 21EX Linear accelerator (Varian Medical Systems, Palo Alto, CA). These measurements were taken with one-layer of a Face-up brass mesh bolus placed on top of the phantom then repeated with the double layer of brass mesh bolus. The results were compared with measurements taken by a Markus ionization chamber under the same conditions in solid water for the following cases: one-layer Face-up of brass, Face-down brass, double brass and 0.5cm and 1.0 cm TE- Superflab bolus.

2.C. Beam profiles.

Gafchromic EBT3 film was used as the benchmark for the beam profiles measured under the brass mesh bolus. 6 × 6 cm^2 Gafchromic EBT3 film pieces were positioned at the center of the

solid water phantom at isocenter with 600 MU/min, 10 × 10 cm^2 and 100 cm SSD. The beam profiles were measured at varying depths (0, 1, 2, 3, 15 and 100) mm. These measurements were repeated for the case of one-layer Face-up brass bolus and double layer of brass bolus. The Gafchromic EBT-3 film was scanned pre-irradiation and post-irradiation using a 48-bit RGB (Red-Green-Blue) transmission film scanner, the EPSON 10000XL Photo Flatbed Scanner (Epson America, Inc., Long Beach, CA), at a resolution of 72 dots per inch (DPI). A 2-dimentional median filter was applied to reduce image noise [19]. For all dosimeter calibration, the measurements were repeated three times and then the average reading was used for analysis. The average uncertainty calculated for the film across all the field size measurements is approximately ± 2.3 % (1SD).

2.D. Exit dose measurements.

The exit doses were measured on the central axis of the 6 MV photon beam using a MO*Skin*™ dosimeter (Face-up orientation). The dosimeter was placed on the surface of the 30 × 30 cm^2 of solid water, with a slab 10 cm thick for the back-scattering material. The gantry of the LINAC was rotated to 180^0 and irradiation was carried out with a 10 × 10 cm^2 radiation field and 100 cm SSD. These measurements were taken without a bolus on the phantom surface and then repeated for one-layer Face-up and then Face-down of brass mesh bolus placed on top of the phantom. The same steps were performed with the advanced Markus ionization chamber to measure the exit dose for the cases of one-layer Face-up, Face-down, double layer of brass mesh bolus and also for the cases of a 0.5 cm and 1.0 cm thick layer of tissue-equivalent Superflab bolus.

2.E. Brass mesh spatial perturbation.

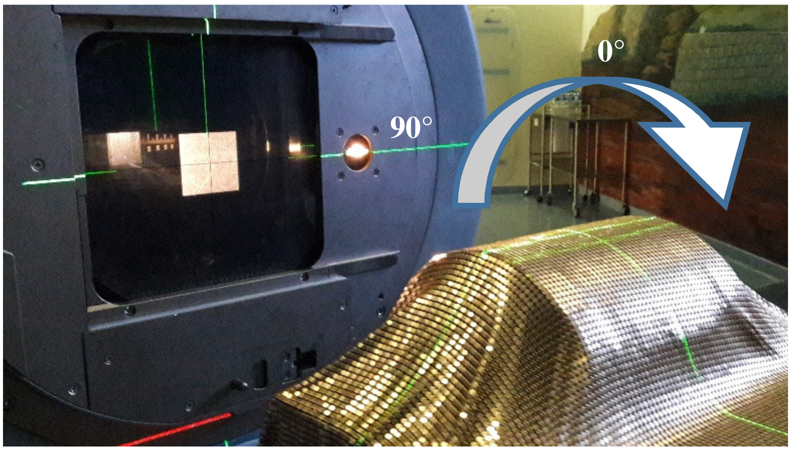
The beam transmission through the brass mesh, both through the brass discs and through the mesh spaces for the case of Face-up and Face-down brass bolus were studied in this section with Gafchromic EBT3 film. The Gafchromic EBT3 film strips were placed on the surface of the solid water phantom. EBT-3 strip irradiated with 300 MU. The dose profiles through the center of the strip plotted. The measurements were performed for 6 MV, 100 cm SSD and 10 × 10 cm^2 field size. The measurements were repeated for Face-up and Face-down brass bolus at surface and 10 cm depth. The beam profile was plotted as the dose as a percentage of d_{max} versus the distance (mm).

2.F. Entrance dose measurements.

The MO*Skin*™ dosimeter, with a faceup orientation, was placed at the central axis of the 6 MV photon beam on the surface of the solid water phantom. The brass discs of Face-up brass bolus were placed above the dosimeter. The measurements were performed under brass discs and then repeated under spaces in the brass mesh. The steps were repeated for the Face-down brass bolus. Finally, the gantry of the LINAC was rotated 180^0 and the same procedures were repeated. The surface doses at the central axis with Face-up brass bolus and with Face-down brass bolus were measured using the MO*Skin*™ dosimeter in Face-down orientation relative to the beam directional from 180^0 in the slab solid water phantom for 10×10 cm^2 at 100 cm SSD.

2.G. Surface beam profile measured on a curved phantom.

To simulate the effect of the breast curvature on the surface doses underneath the brass mesh, surface dose profiles were measured with a 6 MV tangential beam (90^0 tangent field) was measured with 6×20 cm^2 EBT3 film strips which was placed above the curved phantom (20 cm length and 7.5 cm radius). The curved phantom was placed above a 10 cm slab solid water phantom on the couch of the LINAC, as shown in Figure 3. The measurements were performed for 10×10 cm^2 and 100 cm SSD. The measurements were repeated with Face-up, Face-down and double brass bolus and then with 0.5 cm and 1.0 cm TE- Superflab bolus.



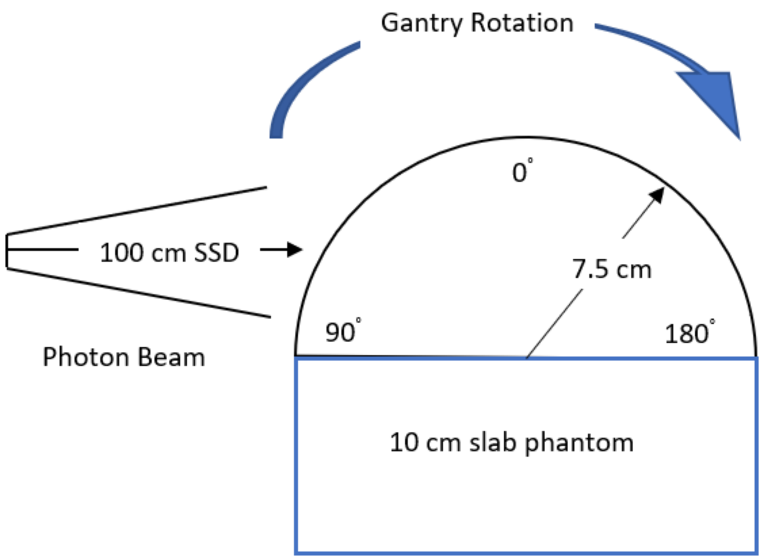


Fig.3 The curved phantom with brass mesh bolus.

3.Results and Discussions

3.A. Attenuation effect of brass mesh bolus

For this research, the polarity effect of the Markus chamber was evaluated. The percentage difference between the positive and negative 300 bias voltage readings was 0.13 %.

The attenuation factor was determined as the ratio of measurements with and without brass mesh on top of the phantom. The brass mesh bolus attenuated the 6 MV photon beam by a factor of 0.994 and 0.986 for one layer, and two layers, respectively. One layer of brass bolus attenuated the 6 MV photon beam by 0.62 % and two layers of brass bolus attenuated the 6MV photon beam by 1.40 %. The attenuation factor of the brass bolus when flipped in the Face down configuration and placed over the phantom attenuated the 6 MV photon beam by 0.57 %. The TE-Superflab bolus attenuated the beam by 1.91 % (0.981) and 3.59 % (0.964) with 0.5 cm and 1.0 cm Superflab thickness, respectively. The presented results show the benefit of the comparatively thin layer of high Z brass material that produces a larger quantity of Compton scattered electrons than an equivalent thickness of tissue and generating very little attenuation of the incident photon beam.

Richmond *et al.* [20] evaluated the attenuation factors for the flattening filter (FF) and flattening filter free (FFF) 6 MV photon beams, and found no difference between them, revealing 0.993 as

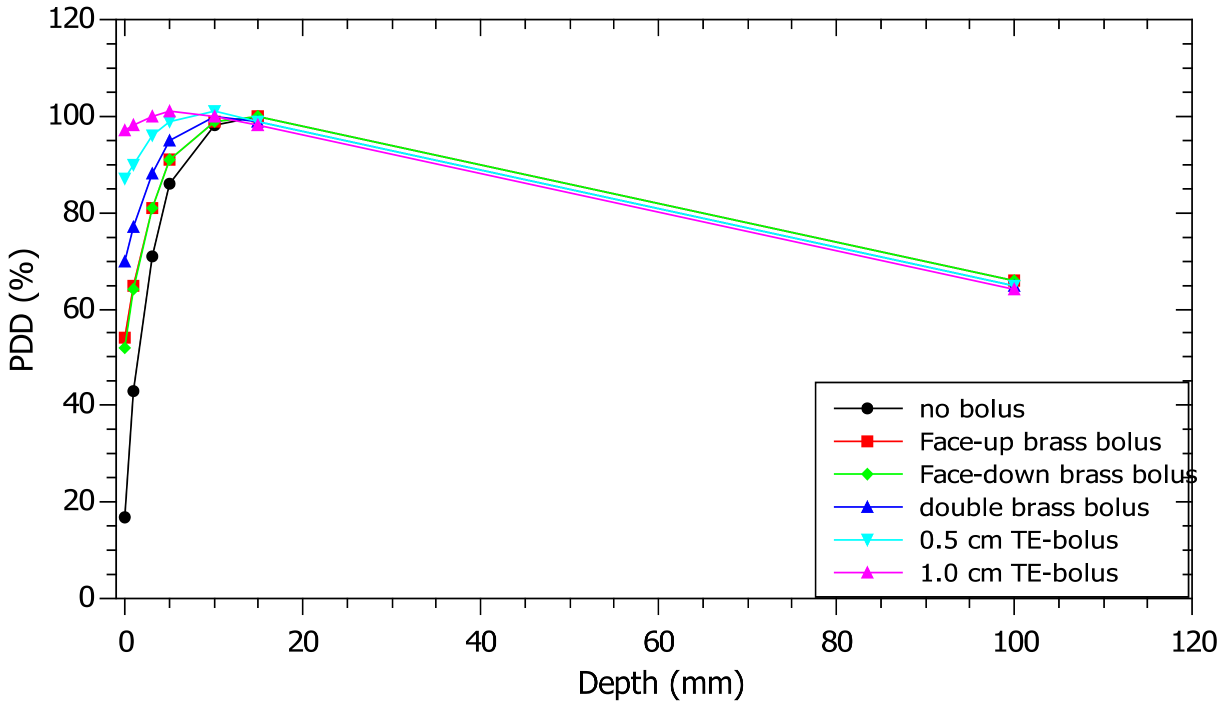
a factor for both FF and FFF beams with one brass layer and 0.987 and 0.986 for 6 FF and FFF with two brass layers bolus, respectively. For 15 MV photon beam, the attenuation factor was 0.995 and 0.989 with one and two layers of brass, respectively [20].

It can be seen that the values of attenuation factors were small and can be easily incorporated in patient treatment monitor unit calculations to account for the attenuating properties of the brass mesh.

3.B. Percentage depth dose (PDD) measurements.

To correct for the over response of the advanced Markus chamber, Rawlinson's formula was used to calculate the correction factor, which was calculated to be 3.6 % at the surface and then decreased with depth.

The comparison of the PDD curves of 6 MV photon beam, normalized to a depth of d_{max}, with a 10×10 cm^2, 100cm SSD, measured with advanced Markus ionization chamber in a solid water phantom for the cases of one-layer Face-up brass mesh bolus, double layer brass mesh bolus and no brass bolus are presented in Figure 4.



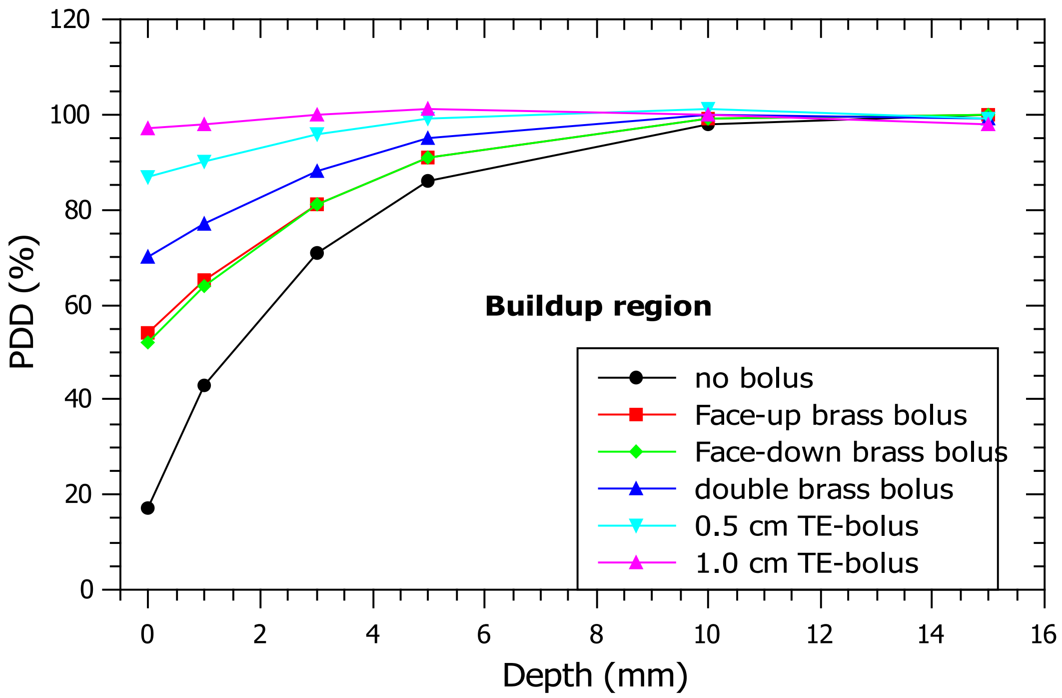


Fig. 4. Build-up PDD curves for 6 MV beam and 10 × 10 cm^2 measured with advanced Markus ionization chamber for the cases of no brass bolus, Face-up brass bolus, Face-down brass bolus, double brass bolus, 0.5cm and 1.0 cm TE- Superflab bolus (SD = 0 %).

Figure 4. shows that by placing brass or TE- Superflab bolus in the radiation field, the PDD curves altered in the build-up region in comparison to the results obtained for the unbolused field irradiation. Both brass and TE- Superflab bolus shifted the PDD to the surface and these results were as expected owing to the photon interactions taking place within the brass and tissue equivalent bolus materials.

The effect of the brass bolus on the PDD curves was less than the TE- Superflab bolus as brass bolus has a smaller tissue-equivalent thickness (2 mm tissue-equivalent thickness according to the manufacturer) than TE- Superflab bolus, and additionally, the beam is hardened by the high Z-brass material.

Table 1 shows the surface dose as a percentage of the dose at d_{max} with the Markus ionization chamber, EBT-3 Film and MO*Skin*™ for different bolus arrangements at 0 mm and 100 mm depth. The brass bolus increased the surface PDD from 22.8 ± 3.8 % to 58.1 ± 5.5 %, 56.7 ± 5.3 %, and 71.9 ± 4.6 % with one-layer Face-up, Face-down and the double layer of the brass bolus,

respectively, as measured with the Gafchromic EBT-3 film, whereas the TE- bolus increased the surface dose to 88.8 ± 5.4 % for 0.5 cm thickness and 97.3 ± 5.3 % for 1.0 cm thickness. The surface corrected PDD measured under the bolus by Markus ionization chamber enhanced the surface PDD from 16.5 % to 53.5 %, 52.3 % 70.1 %m 86.6 % and 97.2 % with Face-up brass, Face-down brass, double brass bolus, 0.5 cm and 1.0 cm TE- Superflab bolus, respectively. The agreement between MO*Skin*^{TM} measurements and Markus ionization chamber measurements were within 3 %. The surface PDD measured under the brass bolus with the MO*Skin*^{TM} dosimeter increased from 19.2 ± 1.0 % to 57.2 ± 1.7 % and 51.4 ± 1.3 % for Face-up and Face-down brass bolus, respectively. The EBT-3 film showed higher responses than the other dosimeters. This disagreement can be explained due to the differences in water equivalent depth (WED) for used dosimeters [18, 21]. The WED of Gafchromic EBT-3 film was determined based on the physical depth and density from the surface to the center of the active layer. The Gafchromic EBT-3 film has 0.153 mm WED [22], whereas MO*Skin*^{TM} dosimeter has a WED of 0.07 mm [23]. The Markus chamber has an effective depth of 0.023 mm [21] .

Table 1 The surface PDD measured with Markus ionization chamber, EBT-3 Film and MO*Skin*^{TM} under brass and TE- Superflab bolus at 0 and 100 mm depth.

0 mm	**no bolus**	**Face-up brass**	**Face-down brass**	**double brass**	**0.5cmTE-bolus**	**1.0cm TE-bolus**
Markus*	16.5	53.4	52.3	70.1	86.6	97.2
EBT-3 Film	22.8 ± 3.8	58.1 ± 5.5	56.7 ± 5.3	71.9 ± 4.6	88.8 ± 5.4	97.3± 5.3
MO*Skin*^{TM}	19.2 ± 1.0	57.2 ± 1.7	51.4 ± 1.3			
100 mm	**no bolus**	**Face-up brass**	**Face-down brass**	**double brass**	**0.5cmTE-bolus**	**1.0cm TE-bolus**
Markus*	65.9	65.6	65.7	65.4	65.1	64.6
EBT-3 Film	68.7 ± 5.2	68.5 ± 5.2	68.5 ± 5.3	69.3 ± 5.3	65.7± 5.3	70.4 ± 4.9

*SD = 0% for Markus ionization chamber.

Manger *et al*. [16] measured the surface PDD curves for a 6 MV beam with an Advanced Markus ionization chamber as 25 % for no bolus, 63 % for one layer of brass bolus and 90 % for 0.5 cm of Superflab bolus, whereas, the measured PDD at 10 cm depth (100 cm SSD) was 68.2 % for no bolus, 68.0 % for brass mesh bolus, and 66.2 % for tissue-equivalent bolus. Richmond *et al*. [20] measured the surface dose for the open 10 × 10 cm^2, 6 MV beam and achieved 14 % of the dose at d_{max} and one layer of brass bolus enhanced this to 44 % where two layers increased the skin dose to 62 % of the dose maximum value.

Gong *et al*. [24] found the 6 MV surface dose to be 15 % lower with one layer of mesh than that with the 0.5 cm of the tissue-equivalent bolus. Our results indicated a 35 % reduction in surface dose, which closely matched the Richmond *et al*. study, where their result was 37%. For two layers of the brass bolus, the surface dose was 17 % less than that with 0.5 cm TE-bolus.

The influences of the bolus decreased with depth. The percentage difference between the doses measured with and without bolus at 100 mm depth, measured with the advanced Markus ionization chamber were evaluated.

The doses measured by the Markus ionization chamber at a depth 100 mm were similar for one-layer brass mesh bolus versus no brass bolus. The percent difference was 0.3 % with one-layer Face-up and Face-down brass bolus versus without bolus, whereas the doses decreased by approximately less than 0.6 % for the double layer of the brass bolus. On the other hand, the percentage difference was 0.9 % and 1.3 % with 0.5 cm and 1 cm TE- Superflab bolus versus without bolus, respectively. Our results presented a good agreement with previous works. Richmond *et al*. [20] found that for 90 cm SSD 6 MV, the changes in the percentage depth-dose curves beyond d_{max} to 25 cm depth, was > 0.3 % between open field and when either one or two layers of brass bolus were added to the phantom surface. Another previously published data reported that the changes in PDD of < 0.7 % when one layer of brass mesh bolus was used with 6 or 15 MV photon beams [11, 25]. Ordonez-Sanz *et al*. [11] results demonstrated that the 5-mm Superflab bolus modifies the doses at depth by up to 2.8 %, therefore the bolus would need to be accounted for in the TPS.

Attenuation of the photon beam increased with additional layers of brass mesh. These results indicated that low energy electrons produced by the brass mesh contributed to the increase in the dose up to 15 mm. Beyond 15 mm depth these electrons no longer contributed dose and attenuation of the beam by the brass mesh becomes noticeable. Thus, the high-density mesh has little effect on the spectrum of the irradiating photon beam, as demonstrated by the negligible change in measured depth-dose characteristics.

Recently published data [11] experimentally determined using thermoluminescent dosimeters (TLDs) the measured PDD at 1mm depth was 50 % for a 6 MV open-field irradiation, which increased to 70 % with the use of the brass mesh bolus. Our measurements showed that the dose increased from 45 % of d_{max} to 66 % at a depth of 1 mm and for double layer, it increased to

79%, whereas it increased to 93 % with 0.5 cm TE-Superflab bolus at the same depth. Furthermore, our data presented the double layer of brass enhanced the PDD to 93.1 % at depth of 3 mm.

S. Gibb *et al*. [26] made measurements at 100 SSD in a phantom perpendicular to the beam central axis using double layers of brass mesh. They found that the PDD at 4 mm depth increased from 77 % with no bolus to 94 % using 3 layers of brass mesh.

Our measurements show that more than two layers of brass mesh bolus are required to achieve similar bolus effect of 0.5 cm of Superflab. This outcome corresponds to Richmond *et al*. [20] work. Other previously published data have pointed out that more than two brass mesh sheets should be added to attain the clinical requirement. Irwin *et al*. [27] indicated that four layers of brass mesh would be required to equate to the bolus effect of 0.5 cm of Superflab, and Gong *et al*. [24] suggested three layers. Fessenden at el. [12] stated in his work that Four layers of a brass fabric, each having an average areal density of 0.25 g/cm^2, are used as the bolus for 6 MV, and three layers are used for 4 MV.

3.C. Beam profiles.

Figure 5.a and 5.b. present the dose profiles measured with 6 × 6 cm^2 Gafchromic EBT3 strip films on the surface and at 100 mm depth in a solid water phantom for the cases of no bolus, Face-up, Face-down brass bolus, double brass bolus, 0.5 cm and 1.0 cm TE- Superflab bolus. The oscillations seen in the profiles (peak-to-trough dose variation) measured under Face-up and Face-down brass bolus were expected due to the mesh brass construction which resulted in inhomogeneous attenuation. The profile measured under the Face-down brass showed an inverted behavior to the Face-up brass bolus. These fluctuations decreased with the double layer of the mesh brass. The PDD profile measured under TE -Superflab bolus was uniform. The effect of the mesh brass construction decreased with depth. Our results displayed that the peak-to-trough PDD variation reduced to 3.1 % and 2.3 % at 1 mm and 2 mm depth, respectively and it was almost uniform at 100 mm depth.

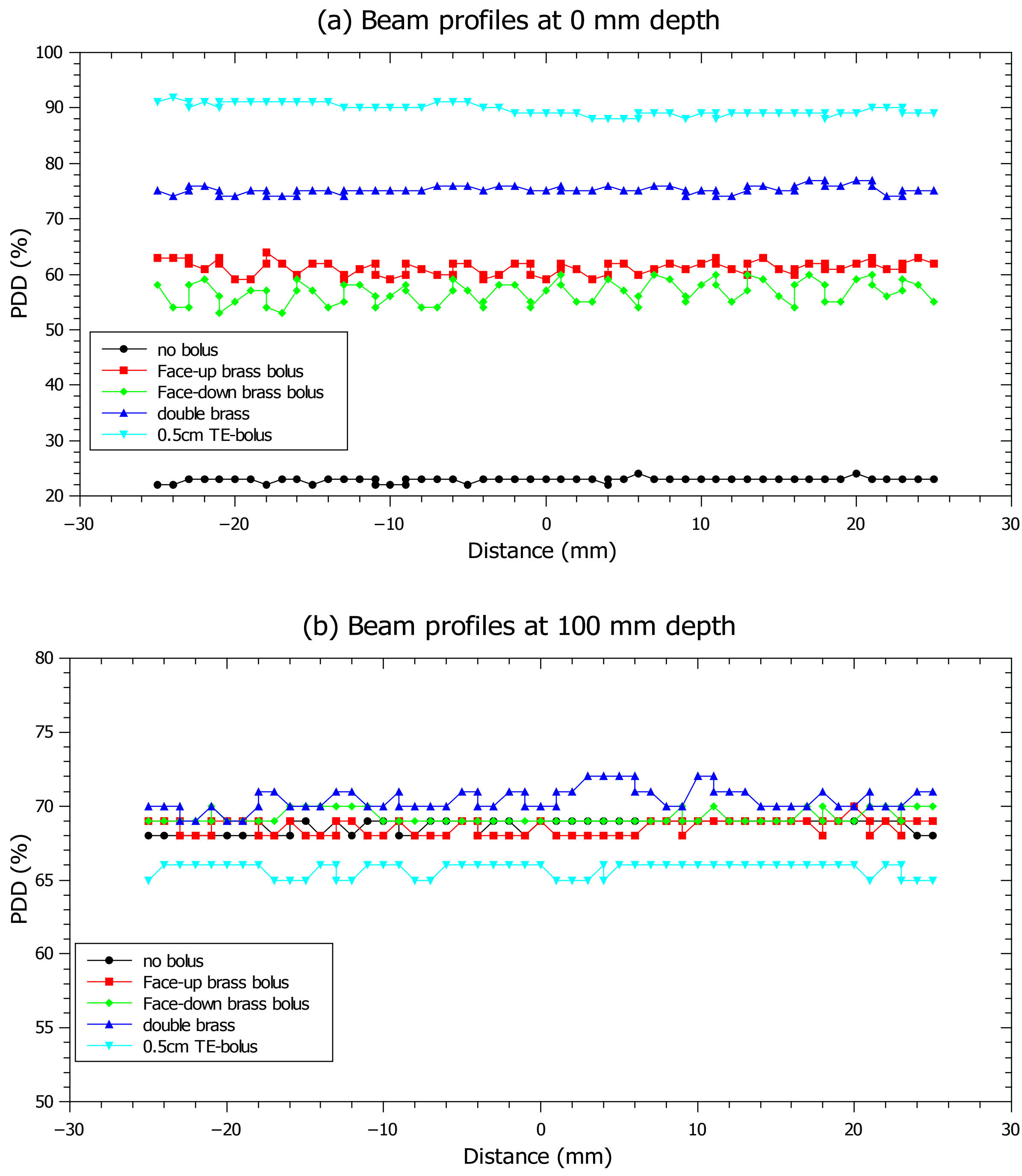


Fig. 5. Dose Beam Profiles measured under brass and TE-bolus at (a) surface and (b) 100 mm depth.

3.D. Exit dose measurements.

The attenuation of the fiber LINAC couch was measured previously in the department during clinical commissioning and found that the fiber couch attenuated only 1 % of the photon beam.

The resulting exit dose measurements are presented in Table 2. With one layer of brass bolus covering the surface of the solid water phantom, the measured exit dose increased to 32 % for both Face-up and Face-down brass bolus configuration as measured with a Markus ionization chamber. The exit dose increased to 37 % for two layers of brass mesh covered the exit surface. The dose enhancement with TE- Superflab bolus were less than the brass. The TE- Superflab bolus increased the dose to 15 %. The measurements performed with MO*Skin*™ dosimeter showed the exit doses were 73.1 % and 72.3 % for Face-up brass and for Face-down brass bolus, respectively.

Richmond *et al*.[20] found that the exit dose for one layer of brass bolus in a 6 FFF MV field increased from 52.1 % to 74.4 % and this result increased to 80.1 % with two brass layers. They also concluded that the high Z brass bolus generates a significant proportion of backscatter, which contributes to a large change in measured dose near the exit surface of the phantom. The dose increase with the brass material much greater than that seen with full backscatter in water [20].

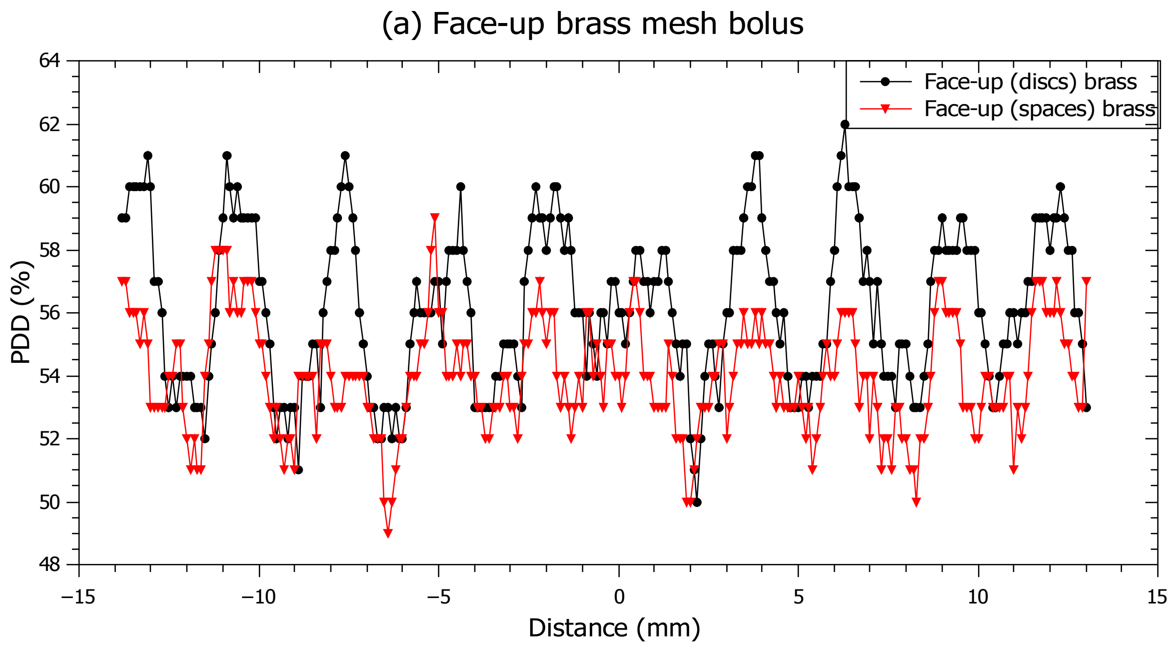
Table 2 Exit dose measured under different cases of bolus with Markus ionization chamber and MO*Skin*™ dosimeter.

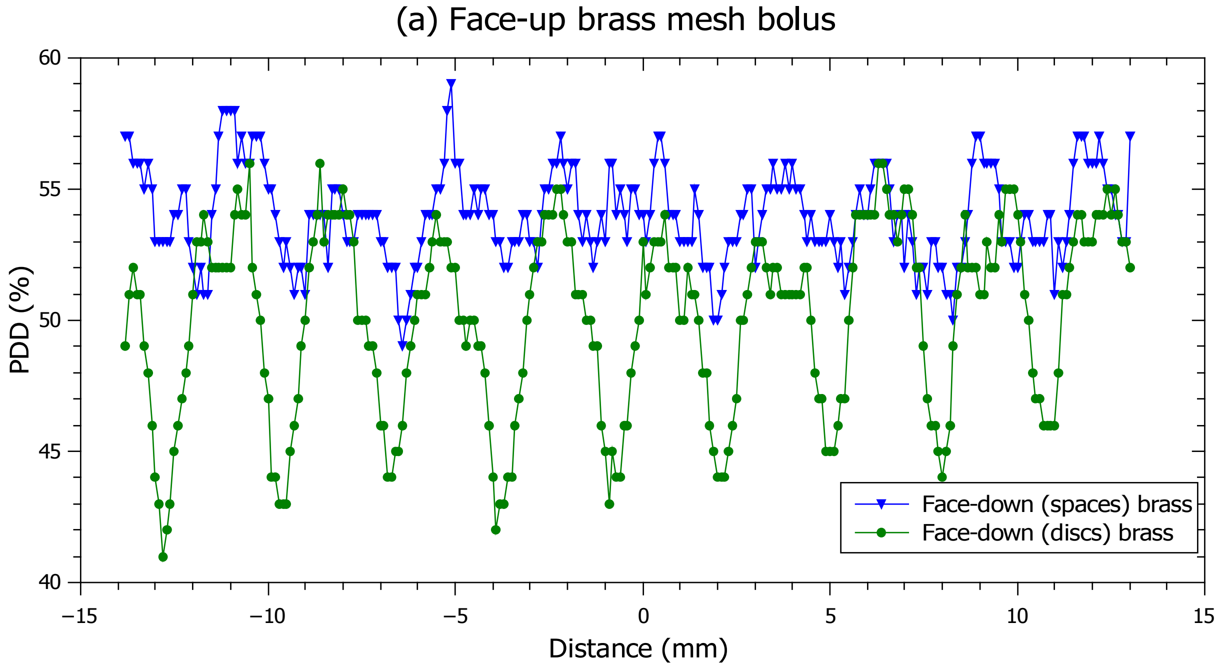
	Exit Dose (%)					
	no bolus	Face-up brass	Face-down brass	double brass	0.5cm TE-bolus	1.0cm TE-bolus
Markus *	53.8	78.7	79.3	85.9	63.1	63.2
MO*Skin*™	47.9 ± 0.5	73.1 ± 0.4	72.3 ± 1.9			

* SD = 0 % for Markus ionization chamber.

3.E. Brass mesh spatial perturbation.

The transmission of the dose through the brass discs and spaces in the mesh of the Face-up and Face-down brass bolus results are presented in Figure 6.a and 6.b and Table 3. The mesh bolus produced a rippled dose profiles, which resemble the mesh pattern.


(a) Face-up brass mesh bolus
Face-up (discs) brass
Face-up (spaces) brass
PDD (%)
Distance (mm)
64
62
60
58
56
54
52
50
48
−15
−10
−5
0
5
10
15


(a) Face-up brass mesh bolus
Face-down (spaces) brass
Face-down (discs) brass
PDD (%)
Distance (mm)
60
55
50
45
40
−15
−10
−5
0
5
10
15

(c)

Fig. 6 a-b. surface PDD (%) measured through the brass discs and spaces in the mesh for (a) Face-up and (b) Face-down brass bolus, (c) EBT-3 Film showing the pattern.

The peak-to-trough dose differences fluctuated from the average measurement through the brass spaces from -5 % to 5 % for Face-up mesh brass and from -6 % to 9 % for Face-down mesh, whereas, the dose transmission difference fluctuated from the average measurement through the brass discs from -5 % to 6 % for Face-up mesh and from -7 % to 6 % for Face-down mesh brass bolus. Richmond *et al*. [20] found in his work that the peak-to-trough dose differences are of the order of 12 % at its maximum.

Table 3 The maximum and minimum surface PDD measured under the brass discs and spaces for Face-up and Face-down mesh brass bolus.

	spaces in mesh brass (%)		**discs in mesh brass (%)**	
	Face-up	Face-down	Face-up	Face-down
$\mathbf{D}_{\mathbf{(max)}}$	58.8	56.3	61.6	59.3
$\mathbf{D}_{\mathbf{(min)}}$	48.8	41.5	50.3	43.3
$\mathbf{D}_{\mathbf{(average)}}$	54.1 ± 4.8	50.2 ± 5.6	56.2 ± 4.5	52.8 ± 5.3

The Face-up mesh brass bolus increased the surface dose to approximately 4 % more than Face-down mesh brass bolus. The average percentage differences of the dose transmission between

spaces and discs were 2.15 % and 2.60 % for the Face-up and Face-down mesh bolus respectively.

3.F. Entrance dose measurements.

The compact size of the MO*Skin*^{TM} dosimeter allowed accurate placement under the discs and spaces of the brass bolus.

The Face-up brass bolus increased the surface dose from 19.2 % to 63.1 % and 51.2 %, as measured under the brass discs and spaces, respectively. Whereas, the increments in the surface dose measurements when the brass bolus was flipped over (Face-down) on the surface of the phantom was a little bit less than the Face-up brass measurements. For the case of Face-down brass bolus, the surface doses enhanced from 19.2 % to 61.5 % under brass discs and to 41.3 % under brass spaces.

These results showed that the brass bolus increased the surface dose. The enhanced dose to the skin at the skin-mesh interface was due primarily to secondary charged particles produced in the mesh brass material. Therefore, as it was noted, that the measured doses under the brass discs were more than the measured doses under brass spaces for both Face-up and Face-down brass cases. The percentage dose enhancement under brass discs were 43.9 % and 42.3 %, for Face-up and Face-down brass bolus, respectively, whereas under brass spaces, the % dose enhancement was 32.0 % and 22.1 %, for Face-up and Face-down brass bolus, respectively. The percentage dose difference between Face-up versus Face-down brass measured were 1.6 % and 3.4 % under brass discs and spaces in mesh, respectively.

Due to the backscatter of electrons, the exit dose was more than the entrance doses, as presented in Table 4.

Table 4 The surface entrance and exit PDD measured with MO*Skin*^{TM} under brass bolus.

	no bolus	**Face-up brass (discs)**	**Face-up brass (spaces)**	**Face-down brass (discs)**	**Face-down brass (spaces)**
Entrance Dose (%)	19.2 ± 3.4	63.1 ± 2.1	51.2 ± 1.2	61.5 ±0.5	41.3 ±2.1
Exit Dose (%)	47.9 ± 0.5	74.1 ± 0.4	72.1 ± 0.4	77.5 ±0.1	67.1 ±3.6

It should be noted that there was a significant backscatter component of dose created by the high Z brass mesh as a megavoltage photon beam exits through the material, as is the case for tangential breast irradiation when compared with the dose build-down effect with no bolus being present.

3.G. Surface beam profile measured on curved phantom.

The measured PDD on the surface of the curved phantom using a 6×20 cm^2 Gafchromic EBT3 film strip using no bolus, Face-up, Face-down, double brass bolus, 0.5 cm and 1.0 cm TE-Superflab bolus with 6 MV tangential field beam (90^0) are presented in Figure 7.

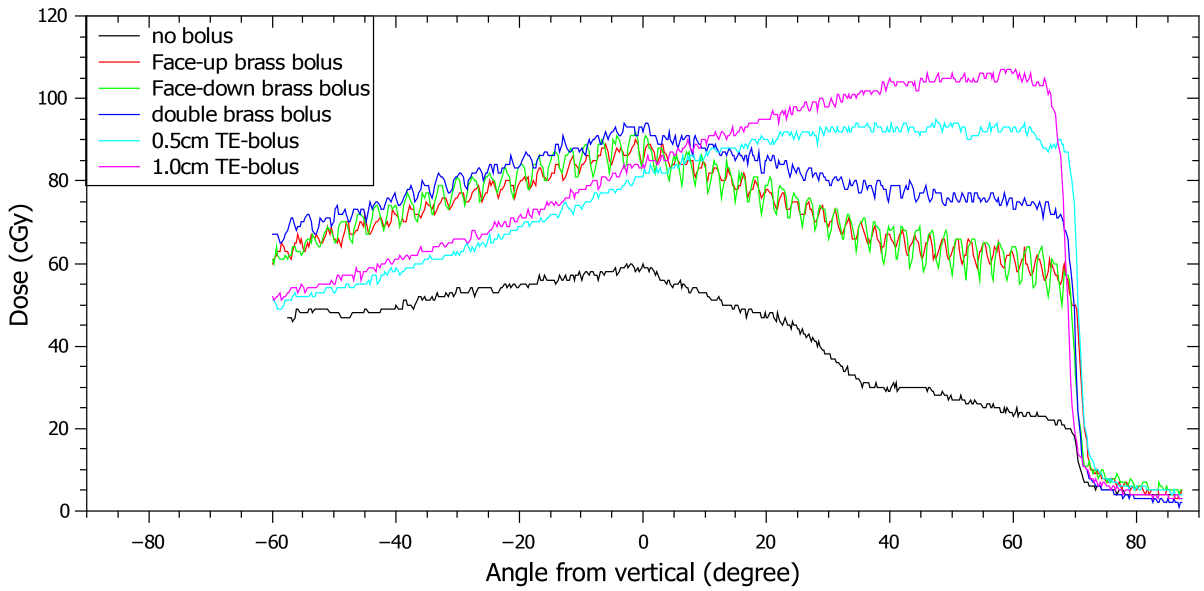


Fig. 7. Surface dose profiles from medial (negative) to lateral (positive), using 6 MV lateral tangential beam (90^0) measured with 6×20 cm^2 Gafchromic EBT3 film. 0° on the x-axis represents the anterior surface of the phantom with ± 90° the posterior edges of the tangential field.

The surface dose profiles for the Face-up, Face-down and double brass bolus cases resembled the profile for the no bolus, whereas, the TE-bolus surface dose profiles presented different pattern, similar to the photon beam profile. For the tangential field, the tissue-equivalent bolus produced a flatter surface-dose profile with a higher average surface dose over the medial to lateral extent of the breast.

As compared with the unbolused irradiation field, the surface dose at the zero degree was enhanced by the brass mesh and TE-Superflab bolus. This was simply because of the dose build-up and backscattering effects created by the two different bolus materials.

The brass mesh was clearly enhancing the surface dose from that seen with no bolus but not by as great an extent as 0.5 cm and 1.0 cm of Superflab. Although two layers of brass bolus placed above the phantom, the surface dose was less than the dose for 0.5 cm TE-Superflab bolus. Moreover, it should be noted that the surface dose for the cases of the brass bolus increased towards the apex of the phantom. This was a result of backscatter dose enhancement on beam exit with the brass mesh.

Our results showed that the surface dose ranged from 24 - 60 % of the delivered dose in case of no brass bolus. The surface dose increased to 62 - 90 %, 64 – 92 %, and 75 – 94 % of the prescription dose for the Face-up brass bolus, Face-down brass bolus and double brass bolus, respectively. The TE- bolus increased the surface dose more than the brass bolus. The surface dose increased to 95 % and 107 % of prescription dose for the 0.5 cm and 1.0 cm TE-bolus, respectively.

The increase in surface dose measured on the curved phantom was similar to the *in vivo* measurements on the IMRT thorax phantom of Manger *et al*. [14] , who found that in the no-bolus case, the surface dose ranged from 40 – 72 % of the prescription dose, with the maximum value occurring at the point where the beam entry was most shallow. The brass bolus surface dose profile resembled the profile for the no-bolus case, except the surface dose was increased to 75 – 110 % of the prescription dose. The surface dose under tissue-equivalent bolus was increased to 85 – 109 % of prescription dose [16]. E. Healy *et al* evaluated the increase in the surface dose for the patients and reported the brass bolus increased the surface dose from 81-122 % of the prescribed dose [6]. It can be seen from Figure 7 that the dose at the phantom surface is clearly nonhomogeneous with brass mesh bolus, compared with using the tissue-equivalent material, this repeat mesh pattern of the brass bolus material is also apparent on the film profiles.

During measurements, the brass mesh bolus was very easy to place on a three-dimensional convex surface of the breast phantom, as shown in Figure 3, while, Superflab bolus cannot

conform to the phantom's surface. There were air gaps between the Superflab bolus material and phantom surface. This outcome was consistent with what other authors found [6, 11, 14].

4. Conclusion

The current article aimed to study the feasibility of using the brass mesh bolus as an alternative to tissue equivalent bolus. From the data presented, it can be concluded that the brass bolus decreases the radiation buildup depth and thereby increases radiation dose delivered to the skin, however, the increases in surface dose for the brass bolus is less than for tissue-equivalent bolus. The brass bolus has some interesting and desirable dosimetric properties over tissue-equivalent bolus. The brass bolus has less attenuation for the 6 MV photon beam, only one treatment plan is required when using the brass mesh throughout the course of treatment since it does not substantially change the number of monitor units (MUs) associated with the plan, and also it has the ability to conform to a curved patient surface with much fewer or no air gaps, which leads to producing more uniform dose distribution, compared with some standard commercially available tissue-equivalent materials. Due to the mesh brass construction, a peak-to-trough dose variation beam profiles were measured at the surface under Face-up and Face-down brass bolus and this fluctuation decreases with the depths. However, the effect of the mesh on surface and superficial dose when used in conjunction with tangential irradiation geometries is complicated and requires careful consideration before clinical use.

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