Original Article

Quantitative Comparison of Dosimetric Data Between the Indigenous Baseplate and Commercially Available Carbon Fiber Baseplate for 6 and 15 MV Photon Energy

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Abstract

Background: This study aims to design an indigenous baseplate (ID baseplate) that is economically viable and dosimetrically comparable for radiotherapy patient treatment. An ID baseplate was designed and manufactured using wood plastic composition materials that are readily available in the market and were compared dosimetrically with the commercially available carbon fiber baseplate (CF baseplate). **Materials and Methods:** Surface dose and beam attenuation properties of both the baseplates (ID and CF) were measured using a parallel plate chamber and compared with the dose calculated from the treatment planning system (TPS). Separate computer tomography images of both the baseplates were acquired by placing solid water phantoms. These images were used for surface dose calculation in the TPS and were validated with experimental measurements. Proper densities were assigned to the couch and baseplates to avoid uncertainties in dose calculations. All measurements were performed at field sizes 10 cm × 10 cm for 6 MV and 15 MV photon beams. **Results:** The percentage surface dose measured for the ID baseplate and CF baseplate was found to be matching for 6 MV beam (98.2% and 97%, respectively); however, for the 15 MV beam, the ID baseplate showed a higher surface dose of 98.6% compared to CF baseplate (87.4%). For the ID baseplate, the percentage difference in the surface dose between that TPS calculated value and the measured values were 1.6% and 1.4% for 6MV and 15MV, respectively. The ID baseplate showed higher beam attenuation than the CF baseplate by 2.2% for the 6MV beam and 3.4% for the 15MV beam when proper electron densities were not assigned. The difference between the TPS calculated dose and delivered dose was achieved within 3% after assigning proper electron density to the couch and baseplate. **Conclusions:** The ID baseplate has shown acceptable dosimetric results and can be an economically viable alternative to the commercially available CF baseplates. The manufacturing cost of the ID baseplate was ten times cheaper than the CF baseplate.

Keywords: Carbon fiber baseplate, couch top, immobilisation device, surface dose measurements

Received on: 03-07-2021 **Review completed on:** 14-01-2022 **Accepted on:** 24-01-2022 **Published on:** 05-08-2022

Introduction

In the last few decades, high-energy photon beams have been predominantly used to kill cancer cells. However, one of the limiting parameters in the usage of high-energy photon beams in radiotherapy is the skin dose. Skin dose is a clinical term that quantifies the value of dose at the surface of the patient. The dosimetric term corresponding to skin dose is called the surface dose. It depends on parameters like scatter dose from the collimator, scattered electron dose, the dose from immobilization devices, and patient support accessories like couch and baseplate. It has been proved that the density of all the patient accessories used has a strong correlation with the skin dose.[1] Therefore, the materials used in these accessories should ideally have a density equal to the air density. Low-density materials such as carbon fiber (CF) and multiple low-density polymers are highly preferred to design the baseplates, which can minimize the beam attenuation and reduce the surface dose to the patients.[1] These materials

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Quick Response Code:

Website: www.jmp.org.in

DOI: 10.4103/jmp.jmp_90_21

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How to cite this article: Gayake UB, Tike P, Bangare M, Raveendran V, Phurailatpam R, George K, *et al*. Quantitative comparison of dosimetric data between the indigenous baseplate and commercially available carbon fiber baseplate for 6 and 15 MV photon energy. J Med Phys 2022;47:145-51.

must also have a higher mechanical strength to hold the patient's weight. CF materials have these desirable properties and are widely adopted by commercial manufacturers for designing couch and baseplates.[1]

The higher costs associated with CF materials have been a major concern for most radiotherapy departments in developing countries like India, as separate baseplates are needed for treatment and simulation. This study aims to manufacture and validate a new cost-effective in-house baseplate of wood plastic composition (WPC). To the best of our knowledge, no studies have evaluated the feasibility of using WPC material for manufacturing baseplate. A detailed dosimetric evaluation was performed to evaluate the indigenous (ID) baseplate for its suitability in radiotherapy practice. Dosimetric parameters viz. surface dose and beam attenuation were measured for the ID baseplate and compared with the CF baseplate.

Materials and Methods

Indigenous baseplate composition and design

The indigenous baseplate was designed and manufactured using a dedicated computer numerical control (CNC) software and an associated in-house CNC machine. WPC sheet of dimension 1 × 1.5 m^2 was purchased from the local market vendor (alstone hybrid WPC Company™). ID baseplate was composed of mixed wood and plastic, having an average core density of about 0.825 g/cc and an average surface density of about 1 g/cc. It is a rigid material with maximum hardness ≥48 shore D and has shown less water absorption. A weight of 135 Kg was kept overnight on the baseplate to verify the mechanical stability and no damage was observed. The tensile strength of WPC material was measured with a universal testing machine at the mechanical lab and was found to break at 142 kg force/cm^2, which is equivalent to 13.92 mega pascal. The mechanical tensile strength for the ID baseplate was <15 mega pascal which matched with the vendor specification sheet. The ID baseplate was made in such a way that a low-density material layer was sandwiched between upper and lower high-density material layers. The CF baseplate also has a similar geometry in which low-density foam density 0.098 g/cc is sandwiched between high-density CF composition layers with density 0.4 g/cc. Both baseplates have a total thickness of 3 cm.

Dosimetric validation

Treatment planning system measurements

Separate computer tomography (CT) images of 1 mm slice thickness were acquired for both the baseplates on a Siemens Somatom CT machine by keeping solid water phantom of dimensions 30 cm × 30 cm × 30 cm over the baseplates. These images were imported into the Elekta Monaco treatment planning system (TPS) (Ver. 5.1.1, Elekta, Stockholm, Sweden). The TPS calculation setup is shown in the figure 1. For surface dose estimation, treatment plans were generated on the imported CT images with a posterior beam (gantry at 180°) of field size 10 cm × 10 cm at 100 cm source to surface distance for 6MV and 15MV beams.[2] The dose was calculated with the Monte Carlo algorithm for 100 monitor units (MU) with a grid size of 2 mm and statistical uncertainty of 0.7%. Hounsfield unit (HU) for both baseplates were also taken from the TPS and values were compared. The surface dose calculation was carried out under three different scenarios explained as bellows:

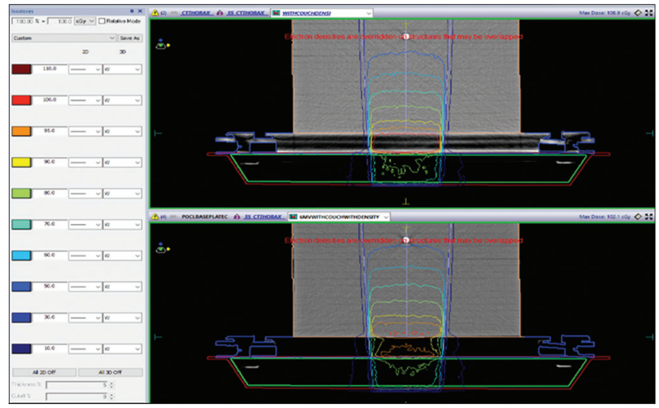

Figure 1: Setup of surface dose measurement by treatment planning system calculation

a. Dose calculated without considering the couch and baseplate: No contours were drawn for couch and baseplate, only the solid water phantoms were considered for dose calculation
b. Dose calculated with the couch and baseplate without assigning proper electron density: Here, the couch and the baseplate were contoured separately, but no electron density was assigned to both the structures. TPS considers the electron density of the existing CT couch in which the scans were taken
c. Dose calculated with proper electron density to the couch and baseplate: The couch and the baseplate were contoured separately and were assigned with proper electron density for dose calculation.

Linear accelerator measurements

Beam attenuation and surface dose measurements were carried out on Elekta's Precise digital linear accelerator (linac).

Surface dose measurements

The surface dose was measured as per the American Association of Physicists in Medicine Task Group report 176,[1] as shown in Figure 2. A plane parallel plate chamber of volume 0.35 cc (SNC PPC350P, Sun nuclear Pvt. Ltd[3]) was used inside solid water phantoms (Sun Nuclear Pvt. Ltd.). Many authors measured surface doses using multiple dosimeters like extrapolation chamber,[1,4] Gaf-chromic films,[1] TLD dosimeter,[1] and plane-parallel chamber,[1,5] etc. The surface dose defined by International Electrotechnical Commission (IEC) 60976 is at a depth of 0.5 mm;[6] however, we had considered the surface dose at 1 mm depth since the effective point of measurement for the parallel plate chamber was 1 mm from the entrance window. Similarly, the TPS surface dose was also taken at 1 mm for comparison.[6,7] The setup used for TPS surface dose calculation was reproduced in linac measurements. The measurements were carried out by shifting the chamber position from 1 mm to 50 mm depth.

Beam attenuation measurements

The beam attenuation properties of the couch and baseplate were measured for both CF and ID baseplates. Measurements were carried out using the 0.6 cc volume (SNC 600C) cylindrical farmer-type ionization chamber in solid water phantoms at 3 cm depth. The attenuation measurements were performed for single gantry angles as well as oblique gantry angles in aisocentric setup. It was measured from 180° to 250° for field size 10 cm × 10 cm and 100 MUs for 6 MV and 15 MV photon energies. The setup for attenuation measurement is depicted in Figure 3.

Results

Beam attenuation factor

The HUs were evaluated for both ID and CF baseplates from the TPS. The mean HU for the ID baseplate is − 222 ± 10.3, and for the CF baseplate, it is − 904 ± 4 HU. Beam attenuation factor for ID baseplate (transmission through couch + baseplate) at field size 10 cm × 10 cm was found to be 0.95 and 0.94 for 6 MV and 15 MV, respectively. The attenuation factors and their comparison for different gantry angles are shown in Table 1.

The graph in Figure 4 shows the difference in the attenuation between the commercial CF baseplate and ID baseplate; the difference in attenuation decreased with the gantry angle for both 6 MV and 15 MV energies. For oblique gantry angles <250° (toward 180°), only a lesser part of the baseplate was coming between the beam and the ionization chamber thereby the beam attenuation was reduced. The graph depicting the attenuation for the ID baseplate was not smooth for 15 MV due to the nonuniformity in its thickness. The maximum difference in attenuation was found at gantry angle 180° as 2.2% for 6 MV and 3.4% for 15 MV as shown in Table 1. The difference in attenuation was found to be greater in 15 MV than 6 MV for ID baseplate.

Surface dose

The percentage depth dose (PDD) values and the surface dose for both the baseplates taken from the TPS for 6MV beam in three different scenarios are shown in Table 2.

The PDD values and the surface dose for both the baseplates taken from the TPS for 15 MV beam in three different scenarios are shown in Table 3.

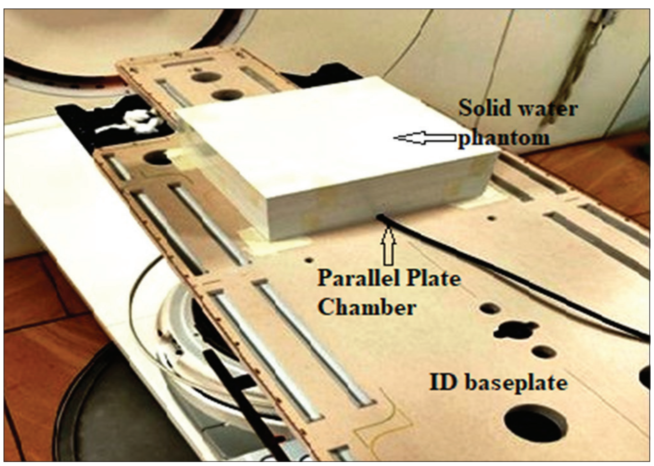

Figure 2: Setup for surface dose measurement with posterior beam

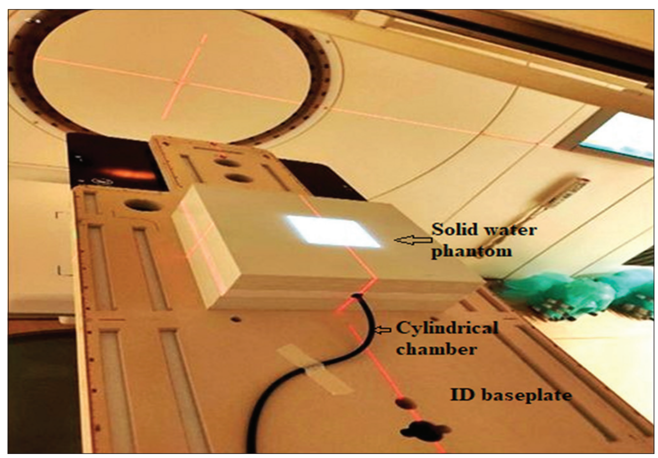

Figure 3: Setup for the attenuation measurement posterior and posterior oblique beam

Table 1: Difference in percentage attenuation between carbon fiber and ID baseplates for 6 MV and 15 MV photon energies

Gantry angle (degree)	6 MV			15 MV		
	ID attenuation (%)	CF attenuation (%)	Difference in attenuation (%)	ID attenuation (%)	CF attenuation (%)	Difference in attenuation (%)
180	5.4	3.2	2.2	6.1	2.7	3.4
190	5.5	3.5	2	6.6	3.2	3.4
200	5.9	3.9	2	6.8	3.7	3.1
210	6.3	4.4	1.9	7	4.8	2.2
220	6.9	5.2	1.7	8	6.1	1.9
230	7.5	6.4	1.1	9.3	7.8	1.5
240	8.2	7.6	0.6	12.5	10.6	1.9
250	8	8	0	14.3	13.2	1.1

CF: Carbon fiber, MV: Mega voltage

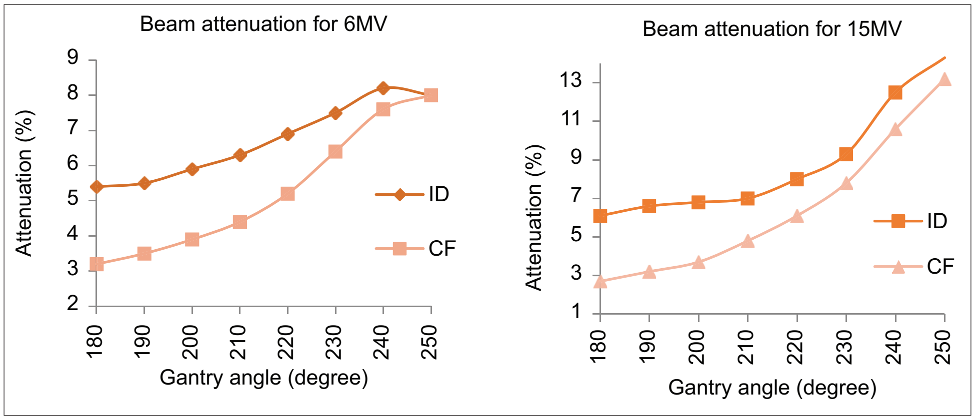

Figure 4: Graphical presentation of difference in percentage attenuation between carbon fiber and indigenous baseplate for 6 MV and 15 MV photon energy

Table 2: Surface dose taken from the treatment planning system for carbon fiber and ID baseplates in three different scenarios for 6 MV beam

Depth (mm)	cGy (%)					
	No couch + ID baseplate	Couch + ID baseplate without proper electron density	Couch + ID baseplate with proper electron density	No couch + CF baseplate	Couch + CF baseplate without proper electron density	Couch + CF baseplate with proper electron density
0	49.2 (50.3)	97.8 (100)	97.8 (100)	48.7 (49.1)	97.1 (97.9)	100 (100)
1	58 (59.2)	97.3 (99.5)	97.2 (99.8)	57 (57.5)	97.5 (98.3)	99.7 (99.7)
2	66.8 (68.2)	96.9 (99.1)	96.6 (98.8)	65.3 (65.9)	98 (98.8)	99.4 (99.4)
3	75.7 (77.3)	96.4 (98.6)	96 (98.2)	75.1 (75.8)	98.4 (99.2)	99.1 (99.1)
4	80 (81.7)	96.1 (98.3)	95.3 (97.4)	80.6 (81.3)	98.7 (99.5)	98.8 (98.8)
5	84.2 (86)	95.9 (98.1)	94.5 (96.6)	86 (86.7)	98.9 (99.7)	98.6 (98.6)
6	88 (89.9)	95.6 (97.8)	93.8 (95.9)	91.3 (92.1)	99.2 (100)	98.4 (98.4)
7	90.6 (92.5)	95 (97.8)	93.6 (95.7)	93 (93.8)	98.9 (99.7)	98.4 (98.4)
8	93 (95)	94.3 (97.1)	93.8 (95.9)	94.8 (95.7)	98.6 (99.4)	98.4 (98.4)
9	94.7 (96.7)	94 (96.4)	93.5 (95.6)	96.5 (97.4)	98.3 (99.1)	98.3 (98.3)
10	95.8 (97.9)	93.5 (96.1)	93.3 (95.4)	97.4 (98.3)	98.3 (99.2)	97.9 (97.9)

CF: Carbon fiber, MV: Mega voltage, cGy: centi Gray

Table 3: Surface dose taken from the treatment planning system for carbon fiber and ID baseplates in three different scenarios for 15 MV beam

Depth (mm)	cGy (%)					
	No couch + ID baseplate	Couch + ID baseplate without proper electron density	Couch + ID baseplate with proper electron density	No couch + CF baseplate	Couch + CF baseplate without proper electron density	Couch + CF baseplate with proper electron density
0	30.8 (30.9)	102.2 (99.4)	103.3 (100)	32.1 (32.5)	84.4 (84.4)	89.6 (89.6)
1	40.6 (40.7)	102.8 (100)	103.3 (100)	40.5 (41)	85.5 (85.5)	90.6 (90.6)
2	49.7 (49.8)	102.6 (99.8)	103.3 (100)	47.7 (48.3)	86.5 (86.5)	91.4 (91.4)
3	57.5 (57.7)	102.4 (99.6)	103.2 (99.9)	61.2 (62)	89.5 (89.5)	93.8 (93.8)
4	62.7 (62.9)	102.3 (99.5)	102.8 (99.5)	63.8 (64.6)	90.4 (90.4)	94.5 (94.5)
5	68 (68.2)	102.3 (99.5)	102.4 (99.1)	67.4 (68.2)	91.6 (91.6)	95.5 (95.5)
6	73 (73.2)	102.3 (99.5)	102 (98.7)	72.5 (73.4)	93.4 (93.4)	96.9 (96.9)
7	76.5 (76.8)	101.7 (98.9)	102.4 (99.5)	76.3 (77.3)	94.7 (94.7)	97.7 (97.7)
8	80.1 (80.4)	101 (98.2)	100.7 (97.4)	79.7 (80.7)	95.8 (95.8)	98.5 (98.5)
9	84 (84.3)	100.4 (97.6)	100 (96.8)	83.4 (84.4)	97 (97)	99.3 (99.3)
10	86.2 (86.5)	99.7 (97)	99.6 (96.4)	85.7 (86.8)	98 (98)	99.5 (99.5)

CF: Carbon fiber, MV: Mega voltage, cGy: centi Gray

The measured PDD and surface dose are shown in Table 4. The surface dose difference between the commercial CF baseplate and the ID baseplate was 1.17% and 11.15% for 6 MV and 15 MV, respectively. Similarly, these values were

0.1% and 9.4% for the TPS calculated surface dose. The depth of maximum dose (d_{max}) shifted by 2 mm when ID baseplate was introduced in the 6 MV beam, while for the 15 MV beam, d_{max} shifted by 9 mm.

The ionization chamber-based PDD measurement data for the CF and ID baseplates are tabulated in Table 4 and graphically shown in Figure 5. Table 5 shows the comparison of TPS calculated and measured surface dose. All the values were found to be within 3% for both energies. According to the IEC 60976,[6] the percentage variation between actual measurement and TPS calculated should be less than 3%. Hence, our result is clinically acceptable and agrees with the result reported by the other authors.[8-12]

Table 4: Comparison of measured percentage depth dose values between ID baseplate and carbon fiber baseplate for two different beam energies

Depth (mm)	PDD (%)			
	ID baseplate	CF baseplate	ID baseplate	CF baseplate
	Energy			
	6 MV		15 MV	
1	**98.22**	**97.05**	**98.58**	**87.43**
2	98.75	98.18	98.83	89.39
3	99.28	98.87	99.25	91.26
4	99.82	99.39	99.67	93.04
5	100	99.74	99.83	94.4
6	99.91	99.91	99.92	95.67
7	99.78	100	100	96.77
8	99.55	99.82	99.92	97.62
9	99.19	99.65	99.67	98.3
10	98.88	99.22	99.54	98.81

Values in bold represent the measured surface dose. CF: Carbon fiber, PDD: Percentage depth dose, MV: Mega voltage

Discussion

This study demonstrated the design of the ID baseplate from the commercially viable WPC. It was dosimetrically validated by comparing it with the commercially available CF baseplate. As baseplate plays a vital role in radiation therapy treatment, the dosimetric impact of the baseplate on the patient body should be considered.[4] The ID baseplate has a higher physical density than the commercial baseplate, but there was no significant difference between these baseplates dosimetrically for the 6 MV beam. The approximate cost of the CF baseplate is between 5 and 10 lakhs Indian rupees (INR), while for designing an ID baseplate from WPC material, the cost is <30,000 (INR) which makes the ID baseplate ten times cheaper than the CF baseplate.

When the treatment couch and the baseplate were not considered for dose calculation, the surface dose for the ID baseplate was 59.2% % and 40.7% for 6 MV and 15 MV, respectively; these were 57.5% and 41% for the CF baseplate. In this scenario, the TPS did not consider the beam attenuation properties of the couch and baseplate, which are physically present during the treatment, thereby resulting in a target under dosage, which is shown in Figure 6. It explained the possible difference in dose if the planner forgets to insert the couch for the dose calculation. After contouring the treatment couch and the baseplate structures and without assigning the

Table 5: Percentage variation of measured and treatment planning system calculated surface dose for 6 MV and 15 MV for carbon fiber and ID

Energy (MV)	Depth (mm)	Couch + ID baseplate (with correct electron density)		Percentage variation	Couch + CF baseplate (with correct electron density)		Percentage variation
		Percentage TPS calculated	Percentage measured		Percentage TPS calculated	Percentage measured	
6	1	99.8	98.22	1.60	99.7	97.05	2.73
15	1	100	98.58	1.44	90.6	87.43	3.62

TPS: Treatment planning system, CF: Carbon fiber, MV: Mega voltage

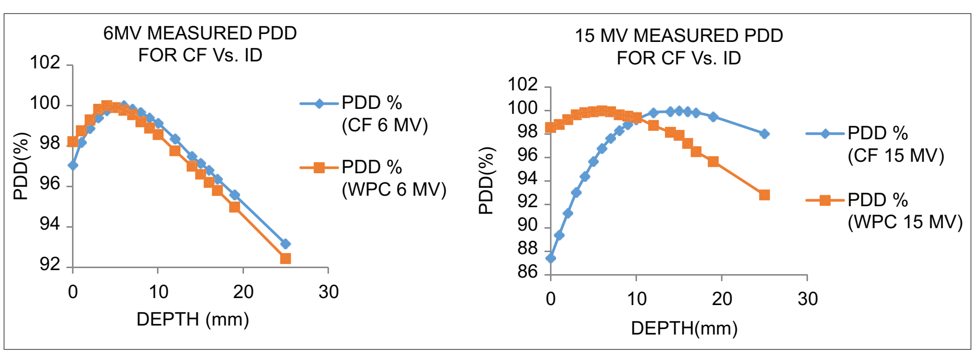

Figure 5: Graphical comparison of measured percentage depth dose values between indigenous baseplate and carbon fiber baseplate for two different beam energies

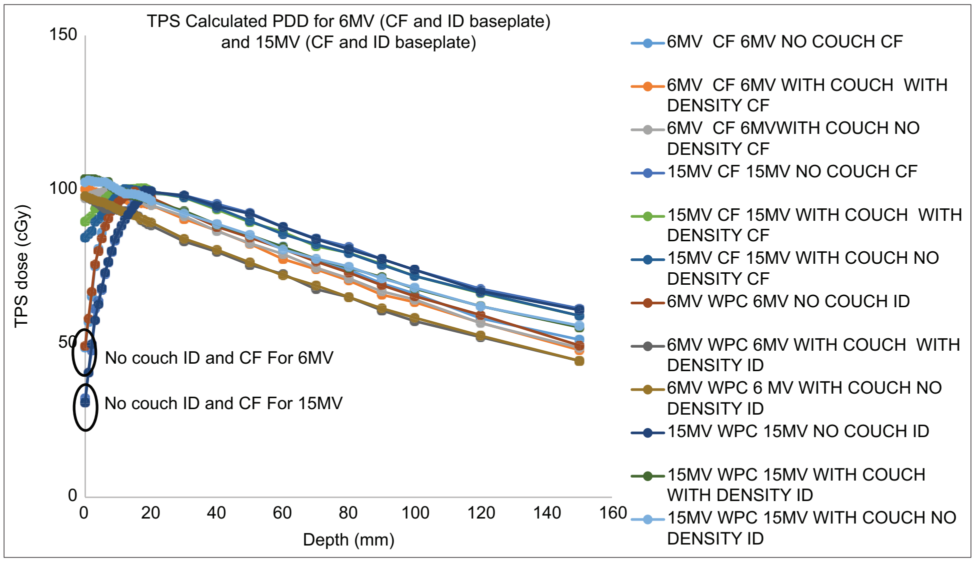

Figure 6: Comparison between the treatment planning system calculated percentage depth doses for 6MV (carbon fiber and indigenous) and 15MV (carbon fiber and indigenous) with three different scenarios (a) Without considering the couch and baseplate (b) Considering the couch and baseplate but without assigning proper electron density (c) Dose calculated with proper electron density to the couch and baseplate

correct electron density value, TPS calculated percent surface dose for 6 MV and 15 MV with ID baseplate was 99.5% and 100%, respectively; with CF baseplate it was 98.3% and 85.5%, respectively. In the above scenario, as proper electron density was not assigned to the couch contour, the TPS would consider it as CT couch in the images with different electron densities, thereby resulting in a wrong dose calculation. To get the correct dose in the TPS, it was essential to assign appropriate electron density to the contours of the couch and baseplate. After assigning the correct density to the couch and baseplate contours, TPS calculated the percent surface dose for 6 MV and 15 MV with ID baseplate was 99.8% and 100%, respectively, with CF baseplate it was 99.7% and 90.6%, respectively. It was observed that by assigning proper electron density to the couch and baseplate, the difference between the TPS calculated dose and delivered dose was achievable within 3%. Many authors had also reported that modeling treatment couch and the baseplate is essential to keep the dosimetric uncertainty within 5%[1] in the dose delivery.

According to the measured data, we have observed that the percentage variation of the surface dose was 1.6% for 6 MV and 1.4% for 15 MV photon energy for ID baseplate, which was acceptable and found to match the TPS calculation. From these results, it can be concluded that the ID baseplate is a clinically acceptable accessory for both photon energies in radiotherapy treatment. The study has been performed for 6MV and 15 MV photon energies only due to the unavailability of other photon energies in our department, but it can also be extended to the other photon energies.

The PDD distributions of the 6MV beam for the CF baseplate and ID baseplate were similar in 1 mm to 50 mm depth, whereas, for 15 MV, the PDD distributions were different. The higher surface dose associated with ID baseplate was mainly due to higher electron density. The material composition of the ID base plate is carbon, nitrogen, oxygen, and hydrogen polymeric chain. This makes the areal electron density of WPC material suitable for Compton and photoelectric effects. At energy greater than 6 MV, the Compton interaction is dominant, which depends strongly on the electron density of the medium. The higher surface dose in the ID baseplate for 15 MV photon energy was due to the secondary electron production in it. The secondary electrons produced from the indirect interaction of photon were responsible for generating the buildup in the PDD curve, which caused to increase in the surface dose.

For higher photon energies, the surface dose is found to be more for the ID baseplate than the CF baseplate; this has to be considered before using it clinically, especially when the majority of the beam contribution is from the posterior direction. This could be a limitation of the ID baseplate. In future, to overcome this limitation, we are working on 3D printed cost-effective and low-density 3D printer filament to design a base plate.[13] As the electron density of the ID baseplate was found to be different at the core and the surface, it is recommended to contour the ID baseplate as separate core and surface components and assign it with proper electron density to avoid the dosimetric uncertainty. For this purpose, the ID baseplate can be modeled and saved to the TPS database as an accessory, which can be easily incorporated into each patient plan.

Conclusions

The ID baseplate is found to be economically affordable and easy to design. When TPS calculated surface dose for ID baseplate was compared with the measured dose, no significant variation was observed for 6 MV. However, in the case of 15MV, there was a significant increase in the surface dose. The difference in attenuation between the TPS calculated dose and delivered dose was achieved within 3% after assigning proper electron density to the couch and baseplate. ID baseplate can be a suitable and alternative cost-effective solution to commercial CF baseplate.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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