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Measurement of Radiation Dose at Abutment Region of Clinically Relevant Photon and Electron Field in External Beam Radiotherapy of Head and Neck Cancers

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ABSTRACT

Purpose: The aim of this study was measurement of radiation dose at abutment region of clinically relevant photon and electron fields in external beam radiotherapy of head and neck Cancers

Methods and Materials: For 3 electron beam 6, 9, 12 MeV with 6 MV asymmetric parallel opposed beam, 6 electron and photon beam plans and summed plans has been generated in eclipse TPS on a water phantom . Plans were delivered separately on RW3 solid water phantom having gafchromic EBT3 film strips placed at 0 to R80 +1 cm depth in the interval of 1 cm for 3 electron beam 6, 9, 12 MeV . Profiles at the abutment regions were analyzed with Fimqa pro 3.0 film dosimetry software.

Results: A hot spot of 32.8%, 36.4%and40.8% and a cold spot of -20%,-22.7% and -21.9% for 6MeV, 9MeV and 12 MeV beams with 6 MV photon beam has been found respectively .A set up error of ±2mm can vary the value of hot spot and cold spot significantly by ±15% to ±20% however, The location of hot spot was 0.14cm to 0.22cm toward the photon field adjacent to the junction line and location of cold spot was 0.18cm to 0.36cm towards electron field. Measured value are in good agreement with the calculated value of TPS with a average difference of 3 to 5% for high dose region and 30-40% variation for low dose region across the junction.

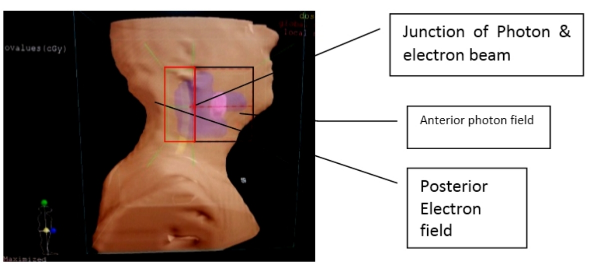
Conclusion: abutment dose can be measured accurately with gafchormic EBT3 film along with filmqapro 3.0 dosimetry system with an uncertainty of 2-3%. The dose at abutment reason is very critical and needs to be evaluated properly and judiciously while treating patients. A 2mm gap between the field's edges can be adopted to reduce the hot spot at the abutment region.

KEYWORDS : abutment dose, EBT3 gafchromic film , asymmetric photon field.

Introduction:

Radiotherapy is widely practiced modality either alone or in combination with chemotherapy in treatment of head and neck cancers .In the conventional and 3D conformal radiotherapy of head and neck cancers a bilateral 6MV photon beam in combination with 6MeV/9MeV/12 MeV electron beam is quiet often used where posterior cervical neck nodes and level 4 nodes are involved [1, 2, 3]. Combined (photon and electron) radiation dose up to 70-72 Gy is given in 35-36 fractions in 7 weeks [4,5,6,1]After 44-45 Gy of 6 MV photon beams to the gross disease with nodes ,the margins of the photon fields are reduced anteriorly to spare the spinal cord(tolerance dose of spinal card 45 Cy[7,8,9,10,]from the photon field and an electron field is used to deliver boost dose of 16-18 Gy in 8 – 9 fractions[1]of suitable energy depending upon the depth of neck nodes. Posterior edge of the photon field is matched with the superior edge of the electron beam on patient skin and thus a photon and electron beam abutted as Shown inFigure-1

Figure-1- Anterior 6MV photon field abutted with posterior electron field



Delivering uniform and adequate dose to the junction area of photon and electron fields due to varied nature in dosimetric and transport properties of photon and electron beam remains a challenge. It has been reported that in combined photon and electron plan some points/Area, the delivered dose could be higher or lower than the prescribed dose and this may result in hot spot and cold spot hence it is imperative to measure the radiation dose across the junction of photon and electron fields.

Junction dose has been evaluated using either XomatV or EDR -2 radiographic films in the abutment region in late 90's. Radiographic film measurement found to be less accurate due to various factors (Chemical processing, temperature dependence, strong energy dependence, finite thickness of the film and low spatial resolution etc)[11,12,13,14,]. Recent advancements and advent of gafchromic film has provided a reliable method to measure relative and absolute dose distribution in a phantom, comparable to ion chamber or other measurement techniques.

[15to24]. However some of the lacuna remains which need to be evaluated systematically:

1. Variation of abutment dose with different clinically relevant electron energy rangesfrom6MeV, 9MeVto12 MeV in combination with 6MV asymmetric photon beam.
2. Measurement of abutment dose at skin and beyond prescription depth.
3. Location of hot spot and cold spot in the target volume and beyond
4. Comparative study of measured and calculated value of abutment dose.

Hence in 3DCRT and conventional setting measurement of accurate dose in the abutment region is clinically important and this study aims to evaluate the same in various clinical setting of radiotherapy of Head and neck cancers.

Material and method:

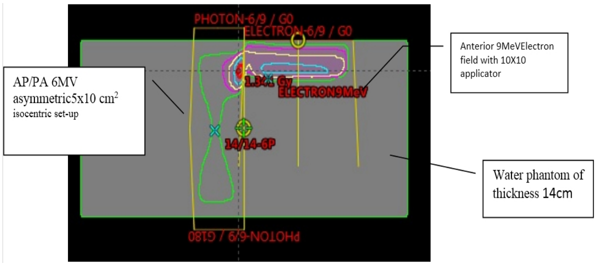
A three dimensional water phantom of the dimension of 30cm (length), 30cm (Width) and 14cm thickness has been developed by using the feature of Eclipse (Varian) 3D treatment Planning system which is equivalent to water in all respect of physical properties needed for the dose calculation.

A 6MV parallel-opposed fields of field size (X-5cm, X1-0, X2-5cm and Y-10cm) having asymmetric collimator were planned to deliver a dose of 1Gy at 7cm depth and dose was prescribed at the is center of 14 cm thick water phantom in a SAD set-up with gantry 0º and 180º for AP and PA field respectively for convenience to place gafchromic film in horizontal set-up to reduce the set-up error.

Another plan created using 9MeV electron field (10cmx10 cm applicator), gantry -0º, collimator -0º and the one edge of electron field is matched with the non-divergent edge of the previously planned photon fields analogous to the one used for head and neck Radiotherapy. Radiation dose of 1Gy was prescribed at the R80 (3cm depth) in SSD set up and dose has been calculated to obtain the dose distribution in the phantom

A composite plan (Figure -2) of both photon and electron fields were generated to evaluate the dose distribution across the junction line.

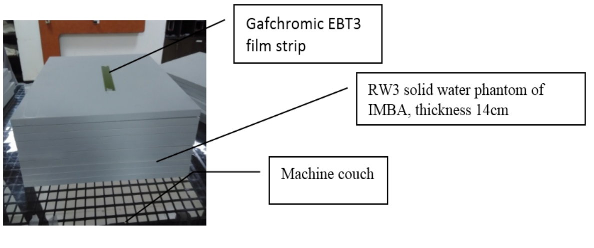
Figure -2: A composite plan of AP/PA photon and anterior electron fields



Both electron and photon plan were transferred using local area network (LAN) to Varian Machine Clinac 2300 C, USA, and Palo Alto. 14 identical plates of RW3 solid water(Make IBA), a water equivalent phantom[25]of size 30cmx30cm x1cm of IBAdosimetry Beijing, mass density -1.045gm/cc^{3}and effective z-0.536 and electron density -3.386x10^{23} e/gm, were utilized to create the water equivalent phantom. All plates were kept on the couch horizontally to mimic the water phantom as created in eclipse TPS for dose planning.

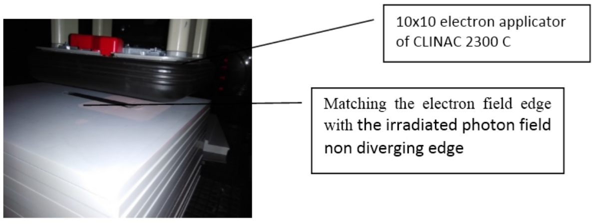
To measure the abutment dose at different depth, 5 rectangular pieces of size (2cmx13cm) from a single gafchromic EBT3 films were cut so that length of the pieces must be aligned along the length of the film. Each piece of the film placed one by one at the center of a solid water phantom plates at 0, 1, 2,3and 4 cm depth as shown in figure 3.

Figure-3: placement of EBT3 film on solid water phantom



Phantom was irradiated with the planned AP/PA 6MV photon fields and then with the 10x10 cm^{2}anterior electron fields where edge of electron field perfectly matched with the asymmetric non divergent edge of 6MV photon field (Figure -4).All gafchromic film pieces were labeled for their orientation and electron beam energy of irradiation and kept in a small envelope for 48 hours as recommended[26]

Figure-4: Set-up for irradiating the gafchormic film with electron beam



Applicator-10x10 cm2, gantry-0, collimator-0 SSD-100 cm

Dose measurement and analysis of the film: A calibration curve was plotted by exposing rectangular gafchromic film pieces of size (5x4 cm2) from the same batch of the film for the known doses of 25cGyto 300cGy by 6MV Beam of clinac2300C after performing the absolute dosimetry as per TRS 398 protocol using 0.65 cc farmer chamber of IBA with "dose 1" electrometer (IBA) as per TRS 398 protocol. All exposed films were scanned by EPSON Expression (11000xL, Japan), in a landscape orientation, with a resolution of 72 dpi and color depth of 48 bit in transmission mode. Calibration curve has been plotted by fimQapro3.0 Ashland, USA, film dosimetry software (SRCHRI, Haldwani) by converting the dose to pixel value / optical density

All irradiated rectangular films (2x13 cm2) by photon and electron fields has been scanned by EPSON Expression (11000xL, Japan), scanner in transmission mode with the similar setting as used for generating the calibration film. Dose across the junction has been measured by the Fimqapro 2016, film dosimetry software. A cross line profile across the junction of photon and electron field has been measured to find the high dose and low dose points and data have been tabulated. Magnitude and location of hot spot and cold spot has been evaluated, any dose value higher than 107cGy is considered as hot spot and below 95 cGy in considered as cold spot as per the ICRU50&62 guidelines [27, 28].

Each line profile of the respective depth has been compared with the line profile generated by the eclipse TPS to find the variation between the measured and calculated value of high and low dose at the abutment region and data has been tabulated in excel for the analysis.

Similarly dosimetric data has been generated for various combinations of electron and photon energies as detailed in Tables 1 and 2

Results: following results were obtained after analysis

A) Results for the perfect match between the edge of photon and electron fields :

Table-1 shows the variation in high dose value for three photon and electron beam combination -6MV with 6MeV, 9MeV and 12MeV electron beam named as a, b and c in the table for the different depth in the solid water phantom

The maximum value of hot spot for the 3 combinations of photon and electron beams a, b, and c was found to be 132.8, 136.4and 140.8 cGy respectively which were 32.8%, 36.4%, 40.8% higher than the prescribed dose (100cGy) respectively.

The minimum value of hot spot for the combination a, b, and c is found to be 128.7, 118.2and114.5cGyrespectively which are 28.7%, 18.2%, 14.5% higher than the prescribed dose (100cGy)

The high dose at the surface is found to be 99cGy, 102cGyand 97.3 cGy across the junction for the 6, 9 and 12 MeV electron beam respectively.

	High dose value for 6, 9& 12 MeV combinations in cGy		
Depth cm	6MV and6MeV (a)	6MV and9MeV (b)	6MV and12MeV (c)
0	95.5	102	97.3
1	128.7	118.7	114.5
2	132.8	136.4	130.3
3	102.5	131.2	140.8
4		105.6	139.7
5			121.7

Table-1 Variation of high dose across abutment region for the 3combination of photon and electron beam energy for the perfect matching of Photon and electron field edges at the junction

Table -2 shows the variation in low dose across the abutment region with depth for 6MeV, 9 MeV and 12 MeV with 6 MV photon. The maximum value of cold spot for the 3 combination of photon and electron beams-a, b, and c is found to be 80,77.3and 78.9cGy for the respective prescription depths(2,3and4cm) of electron energies respectively which are 20%,22.7%,22.1% lower than the prescribed dose (100cGy) and this shows that average value of cold spot for all three energy is 21.6 cGy and there was no cold spot for the blow the prescription depth till 1cm.The minimum value of cold spot for the combination a, b, and c is found to be 44, 44.1 and 44.5 cGy respectively which are at the surface and favorable for the patients except in a condition where neck nodes are very close to the skin.

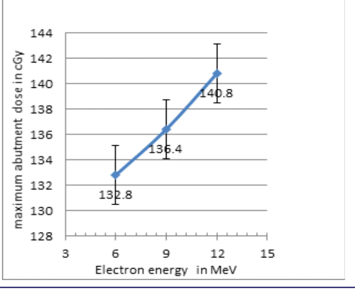
The value of cold spot at 1cm beyond the prescription depth for 6MeV,9MeV and 12 MeV beam was 6.7cGy, 26.5cGy and 49.4 cGy that indicates dose due to rapid fall of electron beam isodose line and it has no effect of adjoining photon field but for the 6MeV and 9MeV beam it can be a matter of importance when depth of spinal cord is between 4 to 5.5cm because in that case an extra dose of 25% and 50% will be received to spinal cord from 9 MeV and 12 MeV beam respectively.

Table-2-Variation of low dose across abutment region for the 3combination of photon and electron beam energy for the perfect matching of Photon and electron field edges at the junction

	Low dose value for 6,9& 12 MeV combinations in cGy		
Depth (cm)	6MVand6MeV (a)	6MV and 9MeV (b)	6MV and12MeV (c)
0	45	44.1	44.5
1	95.3	97.2	98.7
2	80	97.3	98.2
3	6.7	77.3	91.8
4		26.5	78.9
5			49.4

Figure-5 shows the variation of maximum abutment dose with the 3 electron energy is linear with a % increase in the maximum dose of (6MV, 9MeV) and (6MV, 12MeV) combination is 2.7% and 6.02 5 respectively.

Figure-5: Variation of maximum abutment dose with different electron energy with 6MV photon beam



Percentage low dose variation for 9MeV and 12MeV combination with respect to 6MeV beam is found to be -3.49% and -1.375 % respectively.

Hot spot is produced due to lateral bulging of low isodose lines (50%-10%) of electron beam and larger penumbra of the electron beam which increases with the depth [29]and cold spot is produced due to rapid fall of the electron dose beyond 50% isodose line

A) Location of high dose points and low dose points at different depth with different combinations of 6MV Photon and electron energies

Table-3 shows the changes in the Location of hot spot and cold spot for 3 combinations of photon and electron beam energy (6MVand6MeV), (6MVand9 MeV) and (6MV and12 MeV) with different depth in the phantom. It's evident that the hot spot is always toward the photon field area adjacent to junction line. Distance of the hot spot is increasing with the depth for all the three combinations. Minimum , maximum and average distance of high dose points for the each combination is found to be a-(0.13cm,0.5cm,0.31cm), b-(0.16cm,0.34cm,0.23cm) c(0.16cm, 0.52cm, 0.20cm)Mean location of hot spot(dose value >110c Gy) for a, b and c is found to be 0.22cm, .19cm,0.14cm minimum, maximum and average distance of low dose points for the each combination is found to be a-(0.14cm,0.0.18cm,0.27cm), b-(0.26cm, 0.36cm, 0.36cm) c(0.0cm,0.24cm,0.32cm)and location of cold spot(dose <95cGy) for a, b and c is 0.18cm,0.36,0.24cm respectively.

Table-3: Location of high dose points and low dose points at different depth with different combination of 6MV Photon and electron energies

6MV Photon and 6MeV electron with perfect matching of field edge				
	Dose measured (cGy)			
Depth(cm)	max dose	location(cm)	minimum dose	location(cm)
0	95	0.56	45	0.09
1	128.7	-0.13	95.3	0.14
2	132.8	-0.3	80	0.18
3	99.8	-0.5	6.7	0.49
Mean	114.075	-0.22	73.43	0.27
Standard deviation	19.43	0.46	25.78	0.19
6MV photon and 9MeV electron with perfect matching of field edge				
	Dose measured			
Depth(cm)	max dose	location(cm)	minimum dose	location(cm)
0	102	0.56	44.1	-0.71
1	118.7	-0.16	97.2	0.32
2	136.4	-0.22	97.3	0.26
3	131.2	-0.2	77.3	0.36
4	105.6	-0.34	26.5	0.5
mean	118.78	-0.19	78.975	0.36
stdv	15.17	0.38	25.08	
6MV Photon and 12MeV electron with perfect matching of field edge				
	Dose measured			
Depth(cm)	max dose	location(cm)	minimum dose	location(cm)
0	97.3	0.61	44.5	-0.52
1	114.5	-0.16	98.7	0
2	130.3	-0.38	98.2	0.13
3	140.8	-0.37	91.8	0.16
4	139.7	-0.4	78.9	0.24
5	121.7	-0.52	49.4	0.32
mean	124.05	-0.14	76.92	0.17

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(C)Results for the 2mm overlapand2mmgapbetween the edge of photon and electron fields for 6MV and 9MeV electron beam combination.

Table-4shows, 2mm overlap between the 6MV photon and 9MeV electron beam resulted increase in high dose at the prescription depth from 136.4 cGy to 157.8 cGy, 15.69% higher than the dose with perfectly matching of the field edge whereas high dose value decreased from 136cGy to 129.1cGy, 5.35% lower than the dose with perfectly matching of the field edges' for 2mm gap and maximum dose variation was found at 1cm and 2cm depth respectively.

Table-4- high dose variation due to 2mm overlap and 2mm gap between the field edges of 6MV Photon and 9 MeV electron beam at the junction

	High dose value in cGy for				high dose value in cGyfor		
Depth in cm	Perfect matching of the edges	2mm overlap between the field edge's	% variation	Depth in cm	Perfect matching of the edges	2mm gap between the field edge's	% variation
0	101.8	104.9	3.05	0	101.8	99.6	-2.16
1	118.7	156.3	31.68	1	118.7	113.8	-4.13
2	136.4	157.8	15.69	2	136.4	129.1	-5.35
3	131.2	148.5	13.19	3	131.2	129.9	-0.99
4	105.6	108.6	2.84	4	105.6	103.2	-2.27

Table-5 shows low dose variation due to 2mm overlap of photon and electron field edges at the junction line .Value of low dose (cold) spot at the prescription depth has increased from 77.3cGy to 90.9 cGy which is 17.59% higher than the dose with perfectly matching of the field edges whereas due to 2mm gap the low dose value at the prescription depth has reduced from 77.3cGy to 73.8 cGy which is 4.53% lesser than the low dose due to perfect matching of the field edges. The maximum value of cold spot for 2mm overlap and 2 mm gap occurred at 2cm and 1cm depth respectively which are 16.24 % higher and 23.84% lower than the dose due to perfect matching of the field edges.

Table-5: low dose variation due to 2mm overlap and 2mm gap between the field edges of 6MV Photon and 9 MeV electron beam at the junction

	Low Dose value in cGy				Low Dose value in cGy		
	Perfect match	2mm overlap	%variation	depth	Perfect match	2mmgap	%variation
0	44.1	44.5	0.91	0	44.1	43.8	-0.68
1	97.2	101.8	4.73	1	97.2	74	-23.87
2	97.3	113.1	16.24	2	97.3	85.9	-11.72
3	77.3	90.9	17.59	3	77.3	73.8	-4.53
4	26.5	27.1	2.26	4	26.5	26.1	-1.51

A) Comparison of measured value of abutment dose with the calculated value of eclipse treatment planning system

Table -6 shows percentage average difference between measured and calculated value of abutment dose for high dose (hot spot) for 3 combination of photon and electron beam a, b and c and percentage dose difference was 2.34%, 2.29% and 4.4% respectively.

Minimum variation was found to be 0.59 %,-1.14% and 2.29% and maximum variation was found to be 5.57%,5.64% and 6.52% for the three combination a, band c respectively

Table 6: Percentage variation between measured and calculated value for high dose across abutment region of 3electon and photon combination

	Variation			
	%minimum	%maximum	%average	stddev
a)-6MVand 6MeV	0.59	5.57	2.34	2.34
b)-6MVand9MeV	-1.14	5.64	2.29	2.599
c)-6MVand12MeV	0.41	6.52	4.4	2.21
average	-0.05	5.91	3.01	

Table -7 shows percentage average difference between measured and calculated value of abutment dose for low dose (cold spot) for 3 combination photon and electron beam a, b and c and percentage difference was -24.38%,-18.82% and -7.65% respectively .

The Minimum variation was found to be -15 %,-0.82% and1.72% and maximum variation was found to be 44.44%,-43.5% and-15.38% for the three combination a,b and c respectively

The variation for low dose is due to measurement at high dose gradient region and TPS is found to be underestimating the dose as reported by khan et al Johnson and Khan (1994) [30] another possible reason for this could be because of high resolution of gafchromic film measurement as compare to TPS and little contribution could be due to set-up error and air gap introduced due to finite size of film despite the thickness is very less.

Table 7: percentage variation between measured and calculated value for low dose across the abutment region of 3electon and photon combination

	minimum	maximum	%average	stddev
a)-6MV and 6MeV	-15	44.44	-24.38	9.68
b)-6MV and9MeV	-0.82	-43.5	-18.82	25.11
c)-6MVand12MeV	1.72	-15.38	-7.65	28.01
Mean	-4.70	-4.81	-16.95	

Figure-6 and 7, represent the dose variation between measured & calculated value by TPS for High and low dose region for 6MV& 9MeV combination.

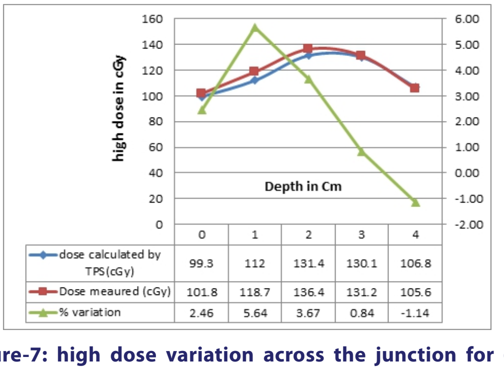

Figure-7: high dose variation across the junction for 6MV Photon & 9MeV electron beam

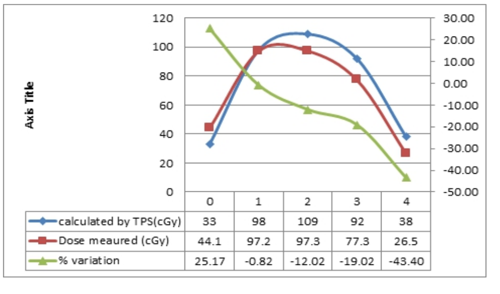

Figure-8: variation of measured low dose across the junction for 6MV photon & 9MeV Electron with the Calculated value by TPS

Discussion:

most of authors have conducted the measurement with 9MeV beam with 6MV/4MV/Co-60 beam thus in this study results of the similar combination of photon and electron beam has been evaluated .Maximum value of hot spot at the abutment region for the 9MeV Electron and 6MV photon beam was found to be 118.7cGy ,136.4cGy and 131.2cGy at 1,2 and 3cm depth respectively for perfectly matching of field edge's which is in close agreement with the result of *Johnson and Khan (1994)*-[30]*,* they have reported a 20% hot spot at 1.6cm depth towards the photon field and dose at other depth was also in close agreement with the another finding reported by *Kemikler (2006)* [32] where they have also reported a hot spot of 30% but the value of cold spot reported from their study is -10% whereas the value of cold spot as per our methodology is 22.7%. This may be due to the fact that they measured the profile or electron and photon beam separately with XV radiographic films and thereafter evaluated the composite profile manually. Sun *et al* (1998 [31] has also assessed abutment dose for laterally opposed isocentric 4 MV non divergent photon fields to a lateral 9 MeV electron field at an extended SSD of 110 cm and they have reported a dose profile variation between 15% hot and 58% hot at 1 cm depth, and a variation between 10% cold on the electron side and 50% hot on the photon beam side at 3 cm depth which is slightly different from our results because of their methodology and use of non-divergent beam which resulted in58% whereas as compare to our result of 31.2% at 3.0 cm depth.

The dose variation due to ±2mm gap has been reported to be +42% to -18%as by them and we have also observed the similar results. value of cold spot as per our result was 77.3cGy at the prescription depth (3cm) but no cold spot was observed for 1.2 cm depth and the value of hot spot for 2mm overlap and 2mm gap is found to be 148.5cGy(+48.5%)and 129.9 cGy(29.9%)and the value of cold spot is found to be 90.9cGy(-10%)and 73.8 (-26.2%) respectively at 3 cm depth which again in good agreement of the result of Kemikler (2006) [32]

Conclusion:

It is feasible to accurately measure the composite dose profile using gafchormic EBT3 film along with filmqapro 3.0 dosimetry system, across abutment region's formed by 3 different electron and photon beam combination at 0 to R80 +1cm depth with an uncertainty of 2-3%.

It is observed that measured results are in good agreement with the TPS calculated value with average difference of 3 to 5% for the high dose value. However, large dose variation has been noted at the lower doses possibly due to high dose gradient region.

A hot spot of 32.8%,36.4%and40.8% and a cold spot of -20%,-22.7% and -21.9% for 6MeV, 9MeV and 12 MeV beams with 6 MV photon beam has been found respectively .

A set up error of ±2mm can vary the value of hot spot and cold significantly by ±15% to ±20%

However, if 20% cold spot is acceptable clinically then the gap of 2mm between the field edges can reduce the hot spot. The location of hot spot varies from 0.14cm to 0.22cm and location of cold spot varies from 0.18cm to 0.36cm from the junction line of the field edges. It can thus be concluded that dose at abutment reason is very critical and needs to be evaluated properly and judiciously on patients plans.

Volume of hot and cold spot is an important factor while accepting the hot and cold spot in the RT plan and this need further evaluations.

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