Original Article

Experimental dosimetry in locally fabricated phantom for endobronchial brachytherapy plan: A phantom study

ABSTRACT

Background: This study is to perform dosimetric analysis in a locally fabricated thorax phantom with the help of radiochromic film.

Materials and Methods: A thorax human body tissue equivalent phantom was fabricated. This phantom was scanned in the positron emission tomography/computed tomography (PETCT) machine and transferred the CT data into the Oncentra Master Plan treatment planning system (TPS). A brachytherapy (BT) plan created in TPS, exported to the high dose rate (HDR) BT machine. Placed Radiochromic EBT3 film dosimeter at the desired locations in the phantom and irradiate on machine with Ir-192 source. The TPS calculated values were compared with film measured values in the Phantom. Doses at five points in each film for each organ at risk were measured and compared with the TPS calculated doses to see the effects of distance on dose variation for analysis purpose.

Results: The film measured doses deviate from TPS calculated doses with –2.5%, –3.2%, 3.8%, 2.4%, 5.3%, 17.75%, –7.1%, –9.4%, and 7.1% variation to Heart, Esophagus, Spinal Cord, descending Aorta, Ipsilateral Lung, Ipsilateral Lung 2 cm depth, pulmonary trunk, coronary artery, and contralateral Lung doses, respectively. In each film out of five points the center point and point closure to the source was having less variation between TPS calculated and film measured doses then other points.

Conclusion: This variation is due to the algorithm used in BT TPS so it is important to perform a verification of the treatment plan before execution in the patient to assure accuracy of treatment delivery. It is cheaper and used as a quality assurance Tool.

KEY WORDS: Film dosimeter, PET CT, thoracic tissue equivalent phantom, TPS

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INTRODUCTION

The treatment of cancer is carried out with radiation therapy techniques whereas two types are available external beam radiotherapy and brachytherapy (BT). In the external beam radiation therapy the dosimetric accuracy procedures are well established but in the high dose rate BT still there is a scope of improvement in accurate dose delivery. The later technique is used where the localized dose delivery is possible and tumor volume is accessible. In the BT a small size sealed radioactive source such as Iridium-192 (Ir^{192}) is precisely placed either inside the tumor or very close to the tumor tissue that is to be irradiated. When a source is used for treatment in BT it follows the inverse square law that delivers a high dose to the tumor and minimal dose to the surrounding normal tissue by rapid dose fall off. This feature of BT reduces the radiation dose to the organs at some distance from the source placed. The radiation source remains at the exact position whether the movement of the tumor occurs with catheter or applicator in place within the patient during treatment.[1]

A remote after loading BT unit is well established system which transfers a radioactive source accurately to the treatment position.[2] The dose calculation in the treatment planning system at a point in high dose rate BT based on the American Association of Physicists in Medicine (AAPM) task Group 43 (TG-43U1), which assumed homogeneous water medium around the source.[3-5] In actual patient different types of tissues are present in between the source and point of interest. The inhomogeneities present around the source affects the dose the researchers investigate distribution. The BT treatment planning system (TPS) adopted

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the three-dimensional computed tomography (3D CT) of the patient for treatment planning that gives the more realistic outcomes of the dosimetry on anatomy of the patient.[1] In the literature there are few studies available on the dosimetric impact of the heterogeneous medium or the applicators either by measurements or Monte Carlo methods.[2] The treatment planning system available commercially does not include the heterogeneity corrections for different types of tissues present around the source in BT dosimetry.[6-8] The dose calculated in the TPS and measured at the desired location has discrepancy that should be accurately find out to correlate the clinical outcome to the parameters of dosimetry. In the BT of bronchial lesion there are some tissues of different densities and that can affect the dose distribution around the BT Ir-192 source.[2]

In the BT, accurate dose distribution is important to achieve in the treatment planning as the dose gradient around the source fall rapidly by increasing the distance. The dose distribution around the source can be measured with experimental and Monte-Carlo methods. Therefore, the dosimeter positioning around the source is important for accurate measurement of dose. The detectors specifically used for this experiment are small TLD, Gafchromic films and ionization chambers. TLD is suitable dosimeter for the small field and accurate dosimetry with its flat energy response and sensitivity.[9] LiF TLD is used for BT verification dosimetry with the AAPM recommendation.

Gafchromic films are recently used in the BT experimental dosimetry.[10-12] EBT3 films are the latest version of Gafchromic films with non-linear dose response. EBT3 films poses high resolution that is beneficial to measure the dose around the source where dose falls rapidly. EBT3 films is having less dependency within its calibration energy range and close to tissue equivalent. Its use in dosimetry is user-friendly and in the clinical busy setup, this method is convenient with cost effective. In the BT, AAPM Task Group 43 (TG 43/TG43U1).[13] recommended a formalism for determining a dose distribution around the sealed source in the water medium, after the various investigator found the dosimetric information on minimize the large variation. The difference between the TPS calculated dose and delivered dose is important to find out because inaccurate treatment could lead to the significant quality of life reduction and late complication to the patient.[14]

There is very less data available on the experimental phantom dosimetry in carcinoma lung BT. Thus, the aim of the study is to verify the doses to organ at risk (OARs) in TPS planned and delivered doses in a phantom designed for site specific with the help of Gafchromic film dosimeters. This study will help in accurate treatment delivery and patient quality of life improvement.

MATERIALS AND METHODS

High dose rate brachytherapy treatment planning system and treatment unit

BT Remote After loading (RAL) unit, Microelectron HDR V3 Nucletron Pvt. Ltd. Make, is used for the phantom irradiation.[15] Oncentra Master Plan (OMP) V3.3 (Nucletron Pvt. Ltd. Make) TPS is used for the planning, consisting Task Group 43 (TG-43) formalism of AAPM. The dimension of HDR Ir-192 source is 3.5 mm active length and 0.6 mm active diameter.[4]

Film dosimeter calibration

The EBT3 Films of size 8" × 10" with LOT number 06142101 were used in the study. The Films were placed in the safe area before it is use to avoid the effects of environmental condition and achieve accurate results. The film calibration carried out in TrueBeam Linear Accelerator (Make: Varian Medical System). The film, 3 × 3 cm^2 size, were placed in the Poly Meth Methyl Acrylate (PMMA) slab phantom at 5 cm depth with source to skin distance (SSD) 95 cm and field size 10 × 10 cm^2, irradiated with the respective monitor units from zero to 700c Gy dose range. The irradiated films were kept for 48 hours in the safe place and after that all irradiated films were scanned in the EPSON Gafchromic film scanner. The scanned data analyzed in image-J software. The pixel value from the irradiated film and unexposed film were used to find out the Mean Optical Density (MOD) value.

Phantom structure

A tissue equivalent phantom was fabricated locally with effective atomic number 6.57 × 1023 electrons/g and electron density 3.36 × 1023 electrons/g material. Dimensions of TV and OARs with external body contour were measured in the TPS for fifteen patients, treated already which helped in designing a tissue equivalent phantom of thoracic site for simulating a carcinoma lung patient. The constructed phantom having almost similar density material to the structures in thoracic region of the patient. Tissue substitutes for lungs two polyurethane foam (density 0.048 g/cm^3) of cubic shape with similar density to lungs, for soft tissue PMMA (density 1.18 g/cm^3) and for bone Delrin (Polyoxymethylene) material (density 1.41 g/cm^3) were used.

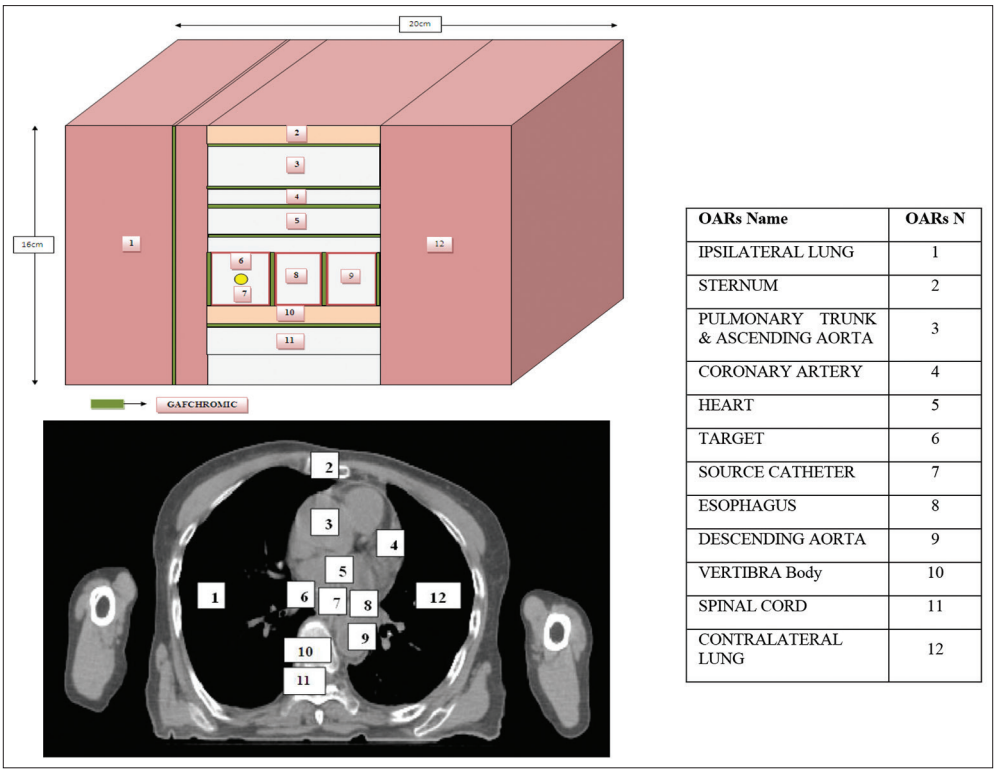
The phantom is fabricated for thoracic cavity site where the OARs having oval or spherical shape. The phantom was made in cubic slab shape to make setup easier for placing samples of the film. For clarity, a comparison between the phantom and the corresponding anatomical region (thoracic cavity) is pictorially presented in Figure 1.

The locations for the films and source catheter were defined properly at the surface of OAR's and in the target volume respectively [Figure 1].

Phantom dosimetric measurements

Simulation and scan of the phantom

The phantom was scanned in the PETCT scanner (GE Healthcare Pvt. Ltd.) with source catheter placed in the target containing the dummy source to simulate the actual treatment geometry. During the scan, geometry of the phantom was made same as the irradiation condition to reproduce the same position to minimize the setup errors between the scanning and treatment



OARs Name	OARs N
IPSILATERAL LUNG	1
STERNUM	2
PULMONARY TRUNK & ASCENDING AORTA	3
CORONARY ARTERY	4
HEART	5
TARGET	6
SOURCE CATHETER	7
ESOPHAGUS	8
DESCENDING AORTA	9
VERTIBRA Body	10
SPINAL CORD	11
CONTRALATERAL LUNG	12

Figure 1: Diagram of the locally fabricated tissue equivalent phantom correlating with thoracic cavity axial image

execution. A set of films were placed at the measurement location, 6F Lumencare Intraluminal catheter was inserted into the target slab and a source dummy was kept in it to visualize in the CT scan images. The CT scan of the phantom was taken and the images exported to the OMP TPS for further planning on it.

Treatment planning and execution on the treatment unit

The CT scan image set of phantoms was imported in the TPS. Target volume and OAR's were delineated in the phantom in TPS. American brachytherapy society (ABS) recommendation was followed to generate a plan in brachytherapy module of TPS.

The source position loaded in the catheter was 5 cm length and dose were 7Gy prescribed at 1 cm diameter from the center of the source. Dose distribution obtained after the calculation in TPS[16] [Figure 2a].

Accurately cut down the EBT3 Film, as per the size of its positioning in the phantom. Film orientation is a very important point to taken care at the time of film cutting. The EBT3 Films were placed at the desired position in phantom for Heart, Spinal cord, Esophagus, Descending aorta, Pulmonary Trunk, Coronary Artery, Contra-lateral Lung (surface), and Ipsi-lateral Lung (surface and at 2-cm depth). The treatment plan was executed on the BT machine [Figure 2b].

After the irradiation the films were taken out from their respective position and named each film very carefully. Stored the films for 48 hours in safe area for its self-development and then proceed for scanning the films.

Film scan and analysis

The irradiated films were scanned in the EPSON 11000XL flatbed scanner and analysis were performed with the help of ImageJ software. The scanning system was used to readout the film response after 48 hours post irradiation.

Then the measured doses were analyzed and compared with the doses at the same position in phantom obtained from the TPS plan. DVH tool was used to assess the data for the analysis.

RESULTS

Film calibration

The pixel values of the irradiated films were found out and then MOD was calculated from the formula:

$$MOD = Log_{10} (P_0/P) \quad \text{Eq. 1}$$

where P_0 is the pixel value obtained from the film kept as background and P is the pixel value obtained from the exposed film.

The relationship between MOD and dose for a particular Lot of a film was plotted as a curve known as calibration curve [Figure 3].

$$D_{(cGy)} = 1878.1\ (MOD)^2 - 66.88\ (MOD)\ [R^2 = 0.9673] \quad \text{Eq. 2}$$

Where, D = absorbed dose and MOD = Optical density

The doses were calculated with the help of the equation obtained from the calibration curve. The film response was nonlinear in nature. Equation (2) is second order polynomial and best fit between the doses and respective MOD of the film. The equation (2) is used in the conversion of film data pixel value (MOD) to dose (D).

The doses calculated in the TPS and measured in the phantom with EBT3 films were compared at the different locations in the phantom shown in Figure 4.

The percentage variation between the doses calculated and measured in the tissue equivalent phantom at different OARs was <10% which infers, TPS underestimate the dose to Esophagus, spinal cord, target top and overestimate the dose for Ipsi-lateral lung where the distance between source and film at surface of esophagus, spinal cord, target top and Ipsi-lateral lung was 1.5 cm, 3.0 cm, 1.5 cm, and 1.5 cm, respectively.

The distance from source to the film position at surface of Ascending aorta and pulmonary trunk (AAPT), coronary artery (CA), descending aorta (DA), heart (H), Ipsi-lateral Lung (2 cm depth) [IL (2 cm)] and target tip (TT) OARs were 5.5 cm, 4.5 cm, 3.0 cm, 2.5 cm, 3.5 cm, and 0.5 cm, respectively. The percentage variation was <15% where TPS overestimate the dose for AAPT, CA, IL (2 cm), and underestimate for DA, H, and TT.

The distance from source to the film position at surface of contra-lateral lung, sternum and target Tip (1 cm) were 4.5 cm, 8.5 cm, and 1.5, cm respectively. The percentage variation was <20% where TPS overestimate the doses to CL and Sternum and underestimate to TT 1 cm film position.

It implies that at the lower distances between source and point of measurement the dose variation was less and as the distance increases the percentage variation increases. At some positions the air inhomogeneity affects the doses either at lesser or far distances from the source.

The doses measured in phantom were obtained from three points corresponding to dose point in TPS for each OARs for analysis purpose. Further dosimetry was done to find out the doses at five positions on same film dosimeters for OARs. The measured dose values for OARs at five positions were represented in Figure 5. The film measured and TPS calculated dose value's variation at five positions for each OARs were shown in Figure 6.

The variation between the two dose values was found out with respect to the distance from the source. The dose value was measured at a center point of the irradiated area and at four points around that center point in the film in phantom. The same steps were carried out for each organ in the phantom and obtained the doses. This shows the variation in the doses among five points in a film that shows that the distance from

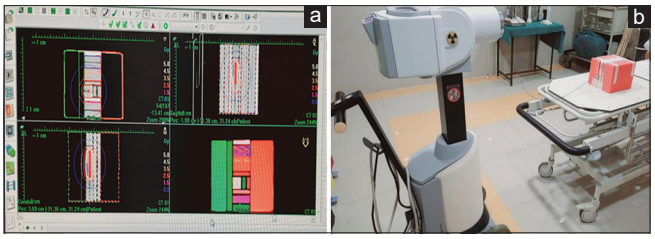


Figure 2: (a) EBBT treatment plan on thoracic phantom and (b) Phantom connected to the microselectron high dose rate machine with source catheter and film dosimeters placed in desired locations

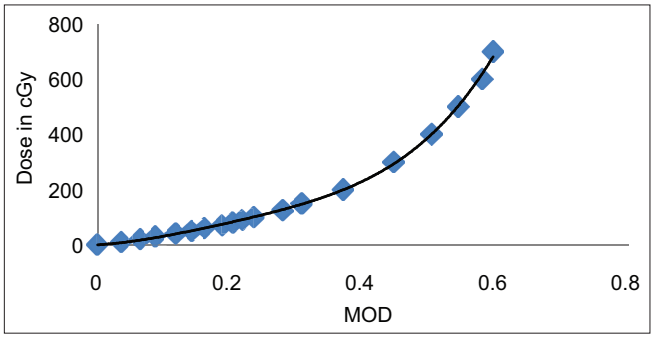


Figure 3: Calibration curve for film dosimeters

OAR Location in Phantom

Pulmonary Trunk (A)
Coronary Artery (B)
Contralateral Lung (C)
Descending Aorta (D)
Esophagus (E)
Heart (F)
Ipsilateral Lung 2 cm (G)
Ipsilateral Lung (H)
Spinal Cord (I)
Target Top (J)
Target Tip 1 cm (K)
Target Tip (L)

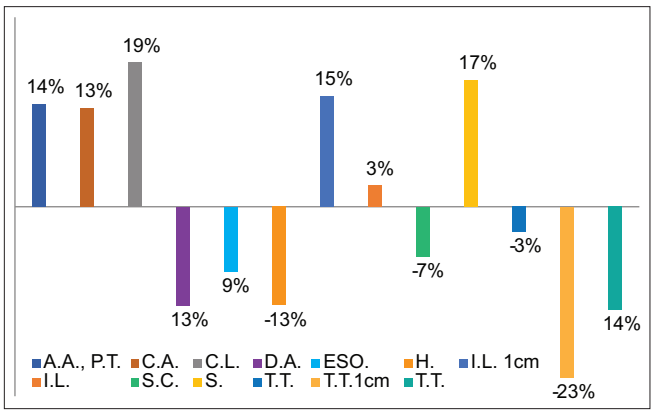


Figure 4: Showing the percentage variation of OAR's doses measured in phantom and calculated in TPS. TPS=Treatment planning system, OAR's=Organ at risk

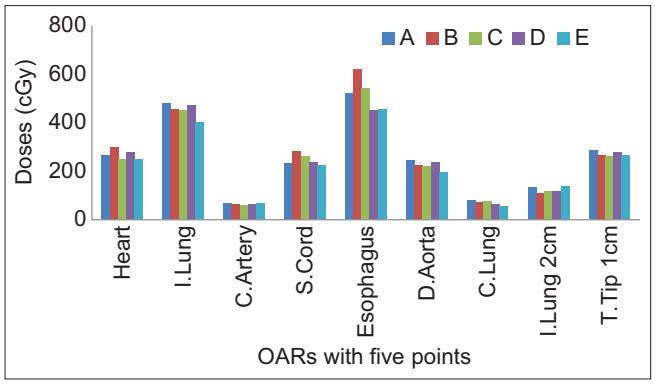


Figure 5: Showing the film measured dose values for OARs at five points on a plane

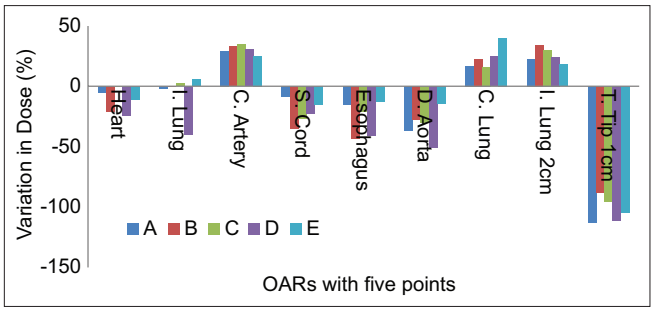


Figure 6: Showing the percentage variation in doses measured at five points between phantom and TPS. TPS = Treatment planning system

the source to the point of measurement in same plane effect the doses.

The film measured doses in the phantom were compared with the doses calculated in TPS for respective OARs position. It showed that there was a variation between the TPS calculated and film measured doses in the phantom, because of distance and dose calculation algorithm in the TPS.[17] In each film out of five points the center point and point closure to the source was having less variation between TPS calculated and film measured doses.

DISCUSSION

In the experimental study, the BT treatment plan verification was carried out in the locally fabricated tissue equivalent phantom material with the EBT3 Gafchromic film dosimeter. The EBT3 film analysis was conducted in the film dosimetry system. The dose measured at the different locations in the phantom for OARs present around the tumor compared with the doses calculated in the TPS at the same location in the phantom. DVH tool was used to assess the data for the analysis. It was observed from the TPS calculated and phantom measured dose values that the dose values measured in the phantom with Gafchromic EBT3 film dosimeter were having less variation at lesser distance and more variation was found at far distances from the source catheter position. The dose values measured at a location in the phantom represent more variation from the TPS calculated dose values. It was due to the air inhomogeneity present in between the film and the source. In the external beam radiotherapy, the advance treatment techniques plans generated in the TPS and a patient specific plan verification quality assurance is carried out where a plan is said to be pass and acceptable for treatment if it follow the gamma index passing criteria that accept less than 5% variation between TPS calculated dose and measure dose value in Electronic portal imaging device (EPID) or in the quality assurance phantom. Here in the BT, dose variation occurs because inverse square law affects the doses around the source.

The dose value measured at the 1 cm away from the tip of the source position is higher due to the air gap of 1 cm in between the film and the tip of the source. The dose value measured at 2 cm away from the source loading position located inside the Ipsilateral Lung was found high from the TPS calculated dose value due to the lung tissue inhomogeneity. The dose value measured at the sternum bone location was lower than the TPS calculated dose due to low doses at far distances from source and film response at the low dose exposure.[18]

The TPS commercially available employ some technique for dose-distribution clinically for calculation.[19] The film measured dose values were vary at some points in phantom from the TPS calculated dose values which might be because of the calculation algorithm in TPS that was not considered the inhomogeneity of tissue present in the phantom. The dose value about the source was affected by the distance of measurement points from the source.[19] and to tissue absorption and scattering.[20,21] Geometric function in the formalism of dose calculation had ignored attenuation and scattering and on the basis of source modeling for activity spatial distribution a correction for inverse-square-law was provided.[15] Dose distribution around the source was calculated by assuming homogeneous medium in the TPS that effects to dose values around the source at least up to 5 cm distance whereas the dose calculated by TPS was higher contrast to the dose measured at Contralateral lung, Ipsilateral lung (surface), Ipsilateral lung (2 cm depth), spinal cord and descending aorta location in phantoms. The result of the experimental study was found like the study performed by the Nikoofar *et al.*[18] who demonstrated that by raising the gap among positions of the source and point of measurement lead to fast fall-off in dose. The dose to the Ipsilateral Lung was differing due to the dose gradient region and film placement position. The measured doses to the position of pulmonary trunk, left coronary artery, Contralateral lung organs which were at large distances having difference due to radiation scattering and attenuation. At the positions nearby the source the doses may be decreased because of the inverse-square-law effect and at distances more the dose reduced due to tissue absorption and it increased by scattering. The distribution of dose was affected with the absorption and scattering at more distances and deviation of about 20% in absorbed dose might cause which depends upon the energy of the source.[20,21] The dose measured at the 2 cm depth in the Ipsilateral lung position was found higher then calculated in the TPS. This might be due to the effect of lung

density and TPS dose calculation algorithm and assumption of homogeneous medium. The phantom was fabricated for the thoracic site where OARs and target volume was transformed to the cubical form from the actual oval or spherical shape. The film dosimeter positioning in the phantom for each OARs was made with very accuracy. To verify the doses measured in phantom and calculated in TPS at film for OARs, the dose was found out at five positions in each film. The dose measured for each organ at risk was compared with doses calculated in TPS at same position. It was observed that the doses were having some variation on the same plane dose points. This variation was due to the distance between the source and the point of dose measurement.

CONCLUSION

The phantom is fabricated locally with the intention of cost effectiveness and its utilization as a Quality Assurance tool for BT treatment plans. As the BT procedures are very important and needs much more attention in treatment delivery so the quality assurance tool for treatment planning system and delivery machine is needed for verification and validation. The BT dosimetry in phantom is useful and applicable in routine practice. The phantom fabricated in this study is cost effective and easy to setup in BT along with the slot provided for Gafchromic film dosimeter which is easy to obtain the planner dose instead of point dose. It is used as the QA Tool for BT treatment plans.

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Conflicts of interest

There are no conflicts of interest.

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