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A new model O Ring isocentric Telecobalt machine with built in imaging system and multi-leaf beam collimation – Type approval inputs for clinical applications

Abstract

It had been emphasized in literature that there is no effect of beam quality in all the megavoltage radiation photon beams towards biological cancer kill. It is also been brought out that linear accelerators have accessory beam modifiers and volume dose modulation facilities compared to simple telecobalt machines. Continuation of telecobalt machines for cancer treatments were recommended even in the era of linacs based on their simplicity and constant beam quality. There is need felt to upgrade the design features in existing cobalt machine designs. Some imported latest cobalt machines have been built with multileaf collimation and intensity modulation capabilities.

In India, a new model O Ring design telecobalt machine, Bhabhatron 3i is designed by M/s PMT Ltd, Karnataka, as latest innovative effort, which is type approved. This report summarizes the basic features of this machine and compares with physical parameters of earlier MLC model Bhabhatron. The built in features include iso-centric KV imager with flat panel detectors, an universal wedge, and an image guided beam delivery designs. The physical parameters acquired towards getting type approval from regulatory authority (Atomic Energy Regulatory Board, AERB, India) are highlighted.

As the dose volume histograms (DVH) with cobalt beam vis-à-vis 6 MV linac photons in test plans are reported in literature to be more or less identical, efforts are being put in to enhance the specifications to intensity modulation capabilities in the latest Bhabhatron 3i machine. As first of its kind this machine is more comparable to latest O Ring model low energy linacs in its performance. In the cancer control programme, such machines will help in meeting the radiotherapy needs of more populated countries with low socio-economic patient loads, and less populated well developed urban regions as well.

Keywords: cobalt radiotherapy, multi-leaf collimator, regulatory approval, dose optimization

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Introduction

In the context of increasing number of non-communicable diseases like cancer in large populated and resource constraint situation, revisit of application of cobalt machine as a resource armamentarium for external beam radiation therapy (EBRT) was recommended even in the era of modern state of the art linear accelerators.[1-3] The continuation of cobalt isotope machines in the radiotherapy applications were recommended by many reports as well as by International Atomic Energy Agency (IAEA) as a cost effective tool with an edge over higher sophisticated linear accelerators. IAEA document[4] refers inclusion of telecobalt equipment for basic radiation oncology facility, for curative treatments. Simple treatments, less power needs, constancy in beam quality, and suitability for treatments of normally encountered type of cancers are some of the important advantages of telecobalt machines which outweigh some of the blames and shortcomings for Co-60 beams, like decaying doserate, repeated source loadings, radiation safety issues and need for waste disposal. Further, by mock trial experiments in cobalt machine,[5] it was recently highlighted that the personnel dose estimate to radiation therapists do not exceed 267 μGy (at 333 TBq, 9000 Ci) in a rare event of 'source drawer stuck'. Cobalt Source changes in the machines are highlighted as one of the disadvantage compared to linacs, but nowadays there is awareness that it is cost-effective based on the total number of patients treated over 8-9 years. In a review, it was highlighted that slightly lower penetration of cobalt due to effective photon energy 1.25 MeV has little effect on delivery of intensity modulated radiotherapy IMRT.[6] 5 mm dose build up has clinical advantage in maintaining entrance doses delivery without presence of immobilization material at the field entrance window; and less lateral electron equilibrium helps in reducing dose uncertainties in the edge of the pencil beamlets. Objective costing have shown that cost per Gy in radiation therapy is less for cobalt teletherapy, and therefore more research is warranted to revisit cobalt RT in practical situations.

Basic radiobiological knowledge highlights that there is no effect of beam quality in all the megavoltage (MV) radiation photon beams towards biological cancer kill, because the basis is indirect effects of radiation by release of free radicals by all low LET photons. India has clinical experience with cobalt beam radiation therapy in the management of cancer for more than six decades. Because of less inter-field separations, telecobalt beam quality, as a MV photon beam, is sufficient to execute treatments in most of the cancer cases. 15 mm dose build up in 6 MV linac beam may be disadvantageous in sub-cutaneous tissue involvements, and thermoplastic materials to compensate for the deep electron equilibrium issues give rise to increase in skin doses. Most of the earlier reports in literature mentioning disadvantage of cobalt-60 teletherapy were pertaining to head and neck radiotherapy, mainly based on skin morbidities, and tolerance issues.[7] Recently the efficacy of cobalt treatments in high grade head and neck cancers was brought out, by employing suitable methods to overcome acute skin and mucosal morbidities.[8,9] Tumoricidal dose of 70 Gy could be delivered to planned treatment volume (PTV) in Overall Treatment Time (OTT) 5 weeks, in recent clinical trials. In another study,[10] need for flattened cobalt beam in straight fields recommended.

In India, modern type Bhabhatron models of telecobalt machines, were functional since past 25 years. These machines have automatic 'shutter closing safety mechanisms' in the event of any malfunctioning of On-Off switching. This is based on micro-processor controlled operation, with remote sensing facility to locate malfunctions. Battery support is helpful in long power shut down time, without interruption in treatment delivery. The previous "non MLC" model were called as Bhabhatron II TAW; and models fitted with multi-leaf collimators (MLC) in place of X rectangular leaves and known as Bhabhatron MLC. Physical parameters of earlier model Bhabhatrons were found in literature.[11-13]

As linear accelerators have beam modifiers and volume dose modulation capabilities, there was a strong need felt for optimisation algorithms for cobalt beam, in treatment planning systems (TPS), as well as execution of either static or dynamic intensity modulation diaphragms. In literature, it is highlighted that the dose volume histograms (DVH) with cobalt beam vis-à-vis 6 MV linac photons in test plans are almost identical.[14,15] A few imported models of latest cobalt machines have built-in multileaf collimation and intensity modulation capabilities. But there are no recent reports in literature on their clinical intensity modulated radiotherapy (IMRT) applications.

A new model O Ring type telecobalt machine has been designed (Bhabhatron 3i) (M/s PMT Ltd, Karnataka) as latest innovative indigenous effort, which is recently type approved. This new design has intensity modulation capabilities, with moving slit windows of individual multileaf collimator capable of working based on the final "intensity modulated treatment plans". In earlier model Bhabhatron II, the cobalt beam was configured in Eclipse treatment planning system for implementation and validation of anisotropic analytical algortithm (AAA).[16] This machine had only rectangular jaws, but Bhabhatron 3i has automated multi-leaf facility. This report summarizes the basic features and physical parameters acquired towards getting type approval from regulatory authority (Atomic Energy Regulatory Board, AERB, India). As first of its kind this machine is more comparable to latest O Ring model low energy linacs in its performance. In the cancer control programme, such machines will help in meeting the radiotherapy needs of more populated countries with low socio-economic patient loads, and less populated well developed urban regions as well.

Materials and methods

Design features

M/s Panacea Medical Technologies (PMT Ltd, India) has recently commissioned another new model cobalt machine at Hassan Institute of Medical Sciences(HIMS)(Fig.1) The built in features include iso-centric KV imager with flat panel detectors, an universal wedge, image guided beam delivery designs. The design geometry of the machine, head, counter weight, X-Ray Tube and Flat Panel Detector Assembly are seen in Fig.2. The outer O Ring structure is same for Panacea make 6 MV linear accelerator, which stands on a base frame, with a guiding motor rotating the gantry structure. Cobalt source position is lower by 20 cm with respect to target position of the linear accelerator to get same isocentre at a distance of 80 cm, remaining same in the geometry. This new model is designed to deliver precise, conformal, image guidance based 3 D Conformal Radiation Therapy(3D CRT), Field in Field(FIF) Intensity Modulated RT, mixing of FIF multiple fields with ARC plans and can generate superior sparing of normal tissue, develop good homogeneity in treated volumes. Ring gantry similar to latest linacs gives good stability for volume dose delivery, using 6D-robotic couch both co-planar and non-coplanar treatments. "Krystal" record and verify (R&V) system matches daily acquired images with original plans, which is added facility very much required in clinical trials for verification of treatments.

The cross section of the Source Head (beam generator) in Source Off condition is shown in Figure 3. Pneumatically operated Source shutter mechanism is shown in Beam ON condition, and Fig.4 shows the Beam OFF condition. Iso-wedge is a stainless wedge block moving parallel to the shutter moving mechanism for source ON-OFF, below the horizontal plane of the primary collimator, and the beam opening cone. Multi-leaf collimator leaves are made up of tungsten 7.5 cm height each, 28 pairs, forming first secondary collimator in X direction, moving in direction perpendicular to the wedge motion, in a lower plane. Y Diaphragms are moving tungsten blocks, which are non-MLC secondary pair of collimators.

There was an model Bhabhatron II-TAW,[17] non-MLC machine earlier. A comparison of Bhabhatron 3i (Bh3i) with its earlier version Bhabhatron MLC (Bh MLC) is outlined in Table-1. The major modifications in Bh 3i are, a) Mounting of source head on a ring gantry with balancing Counterweight which also serves as 'Primary beam catcher'. At 90^{o} to the cobalt beam, there is X-Ray beam from a diagnostic X-ray Tube, and there is a flat panel detector for generating patient's x-ray image for localization and verification (refer Figure 2). b) The beam collimation is of same geometry as earlier model Bh MLC, with following modifications. Bh MLC had source drawer moving to ON position by pneumatic mechanism; whereas in Bh3i the Source drawer is stationary with a tungsten shutter in the path of the beam for Source Off condition (Figure 3), brought to ON position by pushing away the tungsten shutter away from the useful beam (refer Fig. 4 for On-Off stages during treatments). Because of the presence of secondary multi-leaf collimator (28 pairs of moving slits with DC motors), and reduced Source to Skin Distance 80 cm, maximum field openings for clinical use is 25cm x 25cm at 80 cm skin distance. The source head, MLC design, individualized DC motors for operating each MLC vane, and synchronized motion of another X collimator above MLC bank, provides more safety. This adds to further safe beam delivery during intensity modulated beam delivery. The machine is capable of delivering IMRT and VMAT dose deliveries, by incorporating high end Treatment Planning Software in the existing Dosi Soft TPS.

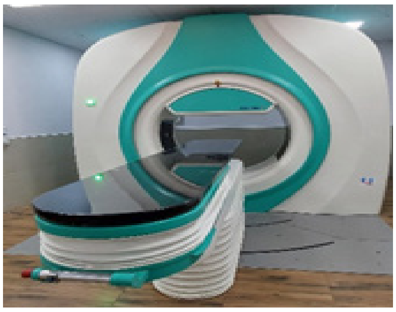

Figure 1 Bhabhatron 3i machine.

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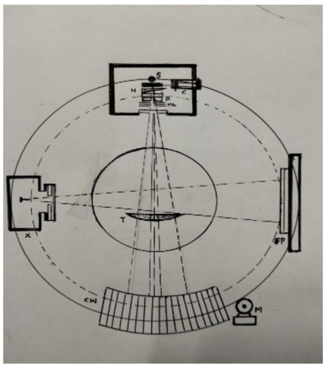

Figure 2 Schematics of Bh3i unit.

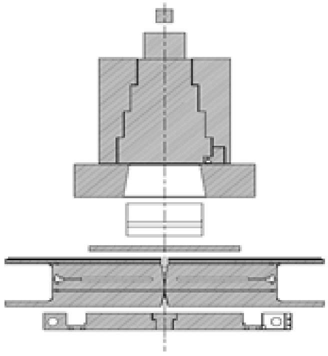

Figure 3 Source off condition.

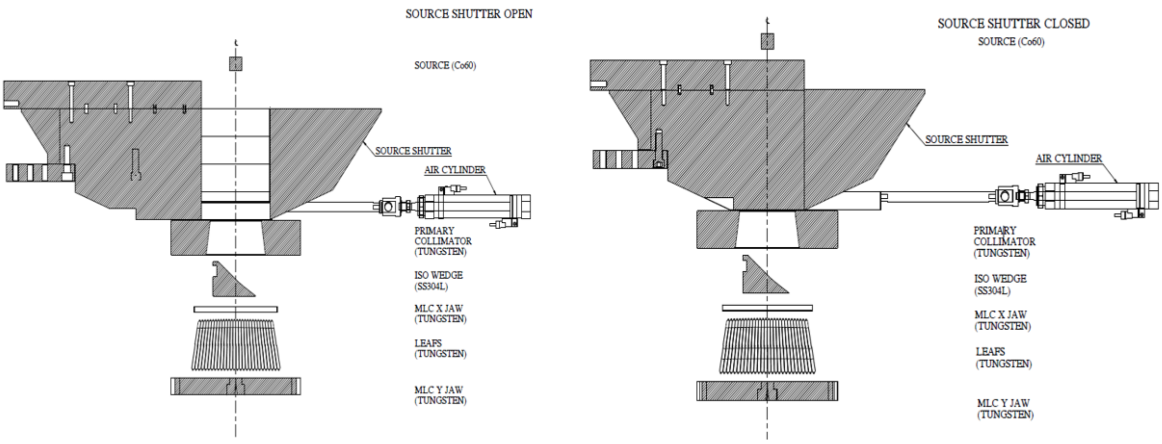

Figure 4 Source head geometry, source ON-OFF shutter mechanisms.

Table 1 Basic differences in the new model Bhabhatron 3i Machine

No.	Specifications	Bhabhatron MLC cobalt machine	Bhabhatron 3i cobalt machine
1	System Capability	Only Cobalt Beam Teletherapy	Cobalt Beam + XRay Localization
			O Ring Type Tunnel Gantry
2	Cobalt Machine Design	Pendulum type with Counter Weight C Arm, optional MLC	With Beam Catcher, MLC Basic. Better isocentre accuracy than Bh MLC
		Without Beam Catcher	
3	Maximum Field Size	20cm x 28cm with MLC Full Open;	25cm x 25cm with MLC
		(Bh II TAW non-MLC 35cm x 35cm)	
4	Source ON-OFF	Pneumatic Source Drawer, Longitudinal Movement of drawer to Source On.	Teletherapy Source position/Drawer stationary. Source On Off by mobile tungsten block below source primary aperture, operated by pneumatic piston. Emergency 0x0 field closing.
		Emergency 0x0 field Closing.	
5	Universal Wedge	Moving Physical Wedge in the path of the beam, below Y axis collimator earlier to the MLC.	Moving Physical Wedge in the path of the beam, below Y axis diaphragms Shutter, earlier to the MLC. Wedge Angle by mixing Open and Wedged beams.
	(Iso Wedge)	Wedge Angle by mixing Open and Wedged beams by software	

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Table 1 Continued...

No.	Specifications	Bhabhatron MLC cobalt machine	Bhabhatron 3i cobalt machine
6	Shielding Tray Attachment	Available	No provision for Shielding Tray because of tunnel enclosure.
7	Intensity Modulation	Capable of only MLC irregular fields. Not designed for intensity modulation capabilities.	With MLC irregular portals forward intensity modulations, stable isocentre to add FIF IMRT Plans and Arc plans to get good optimization. By developing additional software capabilities, feasibility for Inv.Planned dynamic IMRT
8	Localization of treated volume	No localization X-Ray Facility	Isocentric Diagnostic X-Ray facility mounted in O Ring Gantry, with Flat Panel Detector System.
9	Portal Imaging	Not Available.	Not Available.
10	Comparison with O Ring 6 MV Linac	80cm FSD Isocentric without portal imaging; (No KV imaging)	80cm FSD Isocentric without portal imaging, with KV imaging.

Dosimetric measurements

For Beam Scanning, inbuilt Radiation Field Analyser called SCANOMATIKA-water tank with dimensions of 77 x 82 x 44.3 cm^3 equipped with RFA software was used for the beam measurements. The RFA is intended to perform absolute and relative dosimetry required for acceptance testing, periodic QA and commissioning of a radiation therapy system. In-built RFA software was used for analysis of all acquired profile scans. IBA 0.04 cc (CC04) Ion chamber was used in RFA. For 10 x 10 cm field size, values of flatness, symmetry and penumbra were calculated for “in” and “cross” lines. The Radiation Iso-centre verification is performed using Spoke test, with EBT 3-Gafchromic film using 4 non-overlapping beams, at different Gantry and Collimator angles, with slit beams of 0.1 x 20 cm^2, using MLC. The film was scanned with Epson Scanner (EPSON 12000 XL) as per protocol TG-235. Output was measured based on IAEA TRS 398 Protocol, for 10 cm x 10 cm field , SSD 80cm with 0.6cc ionization chamber (Sun Nuclear) at reference depth 5 cm.

Type approval requirements base line

Bhabhatron II type approval validity was outlined by regulatory authority in 2009,[11] which is based on international and AERB recommendations.[16] Collimator transmission was within 2% permitted limits for both X and Y collimators (initially it was 2.1% for X collimator, which was reduced to 1.5% after recommendation by regulatory authority). Maximum radiation leakage in the patient’s plane was 0.19% (< 0.2%) of the absorbed dose value for 10 x 10 cm^2 field output at normal treatment distance (NTD). The average radiation leakage was 0.097% (< 0.1%) both within permitted limits. Other than patient’s plane, the maximum radiation leakage was 0.026% (< 0.5%) which was in permitted limits. The maximum “Rate of Head Leakage radiations” around 5cm was 132.2µGy/h (< 200µGy/h) and at 1m was 18.4µGy/h (< 20µGy/h), against maximum rated capacity of the source head, viz 250 RMM source strength. The entrance surface absorbed dose at 0.5 cm were 63.6% (< 70%) for 10x10cm² field and 79.2% (<90%) for maximum 35 x 35 cm² field. In an user institution,[10] they reported, by TLD studies 29.9% entrance surface dose for Bhabhatron II. We measured radiation leakage values, radiation field analyser (RFA) data, during commissioning, and submitted for type approval of Bh 3i. The salient features and measured parameters are highlighted.

Procedures followed

Testing on the machine comprised of 3 stages. In the factory, without source loading, all electrical, electronic, software controls were thoroughly checked for 3 months. At the site, after installation, all the above checks were repeated. Source loading carried out in May 2023, and dosimetric measurements were performed for 2 months on reproducibility of parameters, confirming its adequacy for clinical use. After satisfactory documentation, in July 2023, Quality Assurance (QA) reports were made ready for submission to regulatory authority. Followed by demonstration of technical and performance of machine to AERB Inspector, further scrutiny of submitted report regulatory authority gave type approval. The Bhabbhatron 3i got licensed after receiving necessary data from the hospital. 2 more machines were licensed by regulatory authority (one in Karnataka and one in Tamilnadu, in India) based on the type approval mentioned, subsequently. Other two machines also had technical parameters as in Table 2, 3 with only minor variations.

Table 2 Mechanical and radiation parameters in Bhabhatron 3i source head

No.	Parameters	Bh 3i measured values	IEC/AERB Requirements
1	Field iso-centre Uncertainty	Gantry 360° 0.23mm	< 2.0mm
2	Field Size 10 x 10cm²	Collimator 0.18mm	< 2.0mm
3	Opposed Fields Match	10.10cm x 9.90cm	± 2.0mm
		100.67mm (Cross Plane)	< 1.0mm
		99.65mm(In Plane)	< 1.0 mm
4	Timer Accuracy	Measured Timer Error ΔT= 0.09”	
5	Wedge Factor(Iso-Wedge)	0.212 (to be mixed with open field for selected Wedge Angle)	
6	Couch Transmission	0.90 (90%)	
7	Dose Rate at NTD=80cm	2.34 Gy/min for Reference Field	
8	Diaphragm Transmission	Mean 0.23% Maximum 0.36%	< 2.0%
9	Leakage Radiations in the Patient’s Plane during Source ON condition.	32 cm Dia = Maximum 0.05%	≤ 0.2%
		77 cm Dia = Maximum 0.02%	≤ 0.2%

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Table 2 Continued...

No.	Parameters	Bh 3i measured values	IEC/AERB Requirements
10	Leakage Radiations outside Patient's Plane during Source ON.	0.04% to Maximum 0.2%	< 0.5%
11	Leakage Radiations in the Patient's Plane during Source OFF condition.	0.0002 mGy/h to 0.007 mGy/h	<0.02 mGy/h
12	Beam Flatness at d= 5mm	5cm x 5cm 103.3% (R_1) 104.9% (R_2)	As per Cobalt Beam
		10 cmx10 cm 104.6% (R_1) 106.7% (R_2)	
		20cm x 20cm 102.9% (R_1) 104.2% (R_2)	
13	Penumbra at 5mm Depth	5 cmx 5cm 9.02mm (L) 8.78mm (R)	≤ 15mm
	(Lower Jaws)	10 cmx10cm 9.83mm(L) 9.59mm (R)	
		20cm x20cm 10.09mm (L) 9.97mm (R)	
14	Penumbra at 5mm Depth	5cmx5cm 10.11mm (L) 10.55mm (R)	≤ 15mm
	(Upper Jaws)	10cmx10cm 11.19mm (L) 11.17mm (R)	
		20cmx20cm 11.85mm (L) 11.88mm (R)	
15	Patient Specific QA for Irregular field (TPS)	2.90 Gy (TPS) 2.85 Gy (Measured)	<2.0%
	Cone Beam CT Check		
16	Correction/Verification	1.06cm (Meas) 1.06cm (Calcu) X axis	
		1.02cm (Meas) 1.02cm (Calcu) Y axis	
		1.15cm (Meas) 1.15cm (Calcu) Z axis	

Table 3 Additional details on Bh 3i type approved machine

No.	Details	Measured values	Tolerance
1	Beam Stopper Transmission Factor	0.02%	0.50%
2	Entrance Surface Dose for 10x10 cm^2	47%	<70%
3	field	0.1 -1.0 RPM	
4	Gantry Rotation Speed	90° 1.82%	
	Output Consistency w.r.t 0° beam	180° 0.11%	<2.0%
		270° 1.18%	
5		0.21mm	Within limits
6	No Field Light. Field Display and Radiation Field Agreements	*Microprocessor set up*	
7	Optical distance indicator(ODI)	0x0 to 25x25	
8	Minimum, Maximum MLC Fields	0.40%	
9	MLC Transmission	Over Travel 6.25cm	
10	X Collimator Asymmetric Field	At NTD (80cm) 1 cm	
11	MLC Width (about 8mm thickness)	Tongue and Groove	
12	MLC Type	0° -0.05± 0.03 (n=6)	
	Reproducibility of Leaf positions	90° -0.04±0.0 1 (n=6)	±1.0mm
	(Mechanical Test –Dial Gauge Method)	270° -0.05±0.01 (n=6)	

Results

As the design of the source head in Bh 3i is modified with respect to earlier version Bhabhatron II(Bh II), the salient features which were earlier approved by AERB consisted of two aspects viz. 1) Radiation generator mechanical and radiation parameters, and 2) Output beam characteristics. In Table-2 the mechanical and radiation parameters of Bhabhatron 3i are summarized. Table-3 highlights various technical features of the machine. Measured transmissions for both X and Y collimators were 0.23% (mean) and 0.36% (maximum) which is within 2% tolerance limits. Compared to Bh II.[12] the design of Bh 3i machine has new type of collimator materials. It could be seen that penumbra in both in X and Y axes decreased because of the presence of MLCs acting as penumbra trimmer for the primary collimator. X Collimator axis is having more penumbra, compared to Y axis; which are pair of lower jaws. Maximum radiation leakage in the patient's plane was 0.04% (< 0.2%) of the absorbed dose value for 10x10cm² field output at normal treatment distance (NTD) during source on condition, which is much less than 0.19% reported for Bh II.[13] Stationary source position with tungsten block shutter provides better reproducibility of exposure, with smaller shutter error. Beam catcher transmission is 0.022%, which totally cuts off primary photon flux. As the reduction of intensity is by a factor 2.2 x 10^{-3} the primary barrier thickness of bunker can be proportionally reduced. Compared to pendulum type mounting, where isocentre support is at the centre of the structure, in this design the guidance of machine rotation is at the base level, this design facilitates much precision of iso-centre. Provision of programmed, controlled source operations, collimator movements, MLC operations etc. enable multiple field uploads from treatment planning system (TPS). This also facilitates future addition of step/shoot or dynamic intensity modulation capabilities. The cone beam radiation treatment portal verifications show perfect agreement with calculated shifts as shown in Table-2. Based on the submitted technical data, approvals for clinical use of this Bh 3i model is granted during 2024. This will help more installations of Bh 3i in future, in India and abroad.

Discussion

This report summarizes the basic features and physical parameters acquired towards getting type approval from regulatory authority (Atomic Energy Regulatory Board, AERB, India). A theoretical modelling of cobalt beam with Bhabhatron model to develop multi-leaf collimator was attempted earlier by using MNCP Monte- Carlo code.[18] They planned 72 leaves (36 leaf pairs) with additional jaws perpendicular to leaf motion having the capability of shaping a maximum square field size of 35×35 cm². The present Bh3i version has maximum useful field size 25x25cm². The built in features include iso-centric KV imager with flat panel detectors, an universal wedge (Iso-Wedge), image guided beam delivery designs. Therefore, this recent design of Indian manufactured telecobalt machine takes into account of all safety features, with patient treatment in the same geometry of CT scanner, and similar precision. As first of its kind this machine is more comparable to latest O Ring model low energy linacs in its performance. The counter weight serves as primary beam catcher reducing primary intensity to about 0.02% which has efficacy to reducing required thickness of primary concrete wall thickness, and also could accommodate in bunkers built for less total head capacity. "Machine's capability on multi-leaf slit movements at various speeds, and also automatic programmed stationary settings were tested by excel sheet feeding through the centralized server and it was confirmed that there is feasibility of IMRT delivery in this machine using in-built Hardware and Software. Our short time clinical experience on Bh 3i gives confidence to execute optimised treatment plans with high accuracy, and capability to treat simultaneously integrated boost (SIB) plans." In the cancer control programme, such machines will help in meeting the radiotherapy needs of more populated countries with low socio-economic patient loads, and less populated well developed urban regions as well.

As an immediate application of this machine, extension of earlier clinical trial in head and neck cancers.[7] is planned. Because there is no shielding tray in Bh 3i, we need to substitute Aluminum tissue compensation (ATC) by multiple MLC opposing fields on the theoretical basis recommended in an earlier work.[20] An earlier theoretical calculations showed the following. For tumor volume in the upper ⅓rd of neck cross section, mixing of parallel opposed open fields (50%) and 45° wedge fields (50%) gives good dose homogeneity (σ_{n-1}=0.67). For tumor volume in the second ⅓rd of neck cross section, mixing of parallel opposed open fields (50%) and 30° wedge fields (50%) gives good dose homogeneity (σ_{n-1}=1.3%). For tumor volume in the middle ½ of neck cross section, parallel opposed open fields (100%) without wedges could provide good dose uniformity (σ_{n-1}=0.5). Another work.[21] elucidated the principle of getting desired angle of wedged photon fields, by mixing of open and 60° wedges in various proportions, which could be applied to get desired uniform pattern of isodoses to achieve dose volume histogram (DVH) in head and neck region as substitution for ATC in Bh 3i. Simultaneously, research efforts in implementing IMRT capabilities in the TPS, and executing in test IMRT plans are in progress.

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Conflicts of interest

None.

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