ACCSCIENCE PUBLISHING

Advances in Radiotherapy & Nuclear Medicine

ORIGINAL RESEARCH ARTICLE

Capability of inversely planned intensity-modulated radiotherapy delivery in Telecobalt Bhabhatron 3i Machine

Ramamoorthy Ravichandran[1]*, Tarani Mondal[1], Manikandan Palanisamy[2], Nandhiya Muthuraman[2], and G.V. Subrahmanyam[2]

[1]Department of Radiation Oncology, Medical Physics Unit, Cachar Cancer Hospital and Research Centre, Silchar, Assam, India

[2]Panacea Medical Technologies Pvt Ltd, Malur, Karnataka, India

Abstract

The Bhabhatron 3i (Bh 3i) is a higher-specification O-ring telecobalt machine manufactured in India. This machine has built-in multileaf collimator (MLC) vanes with high-speed motors for executing dynamic inverse planned intensity-modulated radiotherapy (IP-IMRT). This machine's ability to deliver IP-IMRT is validated. Dosimetric measurements carried out in Bh 3i were compared to the TrueBeam Varian linac, available in another hospital. Measured radiation field analyzer data of Bh 3i were configured in the treatment planning system (TPS) on a request basis, and a temporary license was obtained from a TPS manufacturer, M/s Prowess, USA. Quality assurance measurements were carried out on the planned dose distribution for test IP-IMRT plans, downloaded from the American Association of Physicists in Medicine Task Group 119 (TG 119). MLC leakage value in Bh 3i was much lower than that of the TrueBeam linac. MLC settings remained constant in all gantry orientations. The dynamic dose delivery patterns in Bh 3i and the TrueBeam linear accelerator were similar. Static forward-planned multiple MLC field IMRT with the same isocentre produced good treatment plans. Dynamic IMRT planned on TG 119 test cases of tumor volumes demonstrated satisfactory conformality and homogeneity. Doses to organs at risk were acceptable as per norms. It was found that treatment plan goals are achievable in Bh 3i IP- IMRT, similar to the TrueBeam linac. The new Bh 3i cobalt machine can deliver IP-IMRT for cancer treatment. Obtaining a permanent license for the required TPS software is a high priority to secure the further clearances needed for clinical use.

Keywords: Bhabhatron 3i; Intensity-modulated radiotherapy; Multileaf collimator leakage; Conformal radiotherapy; Inverse planning

***Corresponding author:**
Ramamoorthy Ravichandran
(ravichandranrama@rediffmail.com)

Citation: Ravichandran R, Mondal T, Palanisamy M, Muthuraman N, Subrahmanyam GV. Capability of inversely planned intensity-modulated radiotherapy delivery in Telecobalt Bhabhatron 3i Machine. *Adv Radiother Nucl Med*. 2026;4(3):026230021. doi: 10.36922/ARNM026230021

Received: June 2, 2026

Revised: August 12, 2026

Accepted: August 26, 2026

Published online: September 14, 2026

Copyright: © 2026 Author(s). This is an Open-Access article distributed under the terms of the Creative Commons Attribution License, permitting distribution, and reproduction in any medium, provided the original work is properly cited.

Publisher's Note: AccScience Publishing remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

1. Introduction

Continued use of telecobalt machines for radiotherapy is recommended in the literature even during the advent of linear accelerators.[1,2] In a debate on whether cobalt should be used for radiotherapy, senior experts in the field opined the following important points: (i) Cobalt beam quality has clinical efficacy and favorable radiobiological effects, vis-à-vis high-energy linear accelerator photons; (ii) if a multileaf collimator (MLC) is available

in cobalt machines to treat irregular tumor volumes and reduce the dose delivered to risk organs, and with more technologically advanced automated design, they will be able to use the high-tech telecobalt machines efficiently and cost-effectively.[3] In a study to examine dose to superficial nodes in head and neck, the 6 MV beam quality revealed under-dosing of superficial neck nodes, and beam spoilers had to be placed upstream from the patient.[4] Application of telecobalt beam quality for clinical purposes is especially relevant to head and neck tumors, which are prevalent at 30%–50% throughout the Indian sub-continent. Because head and neck malignancies have superficial nodes, a 15 mm dose build-up is essential for 6 MV beams. At the same time, thermoplastic material (which also provides dose build-up) can cause unacceptable skin morbidity. In clinical research at our center, telecobalt beam quality, tissue compensation, and skin-sparing effect preservation have shown promising results for high-grade head and neck tumors.[5] A cancericidal dose of 70 Gy in five weeks, in 35 fractions, could be delivered with acceptable morbidity in skin and mucosa. In breast conservation management, high-dose-rate brachytherapy has been shown to be a solution for boost, along with cobalt radiotherapy (RT), demonstrating the use of cobalt in managing early breast cancers. For more than seven decades, cancer of the uterine cervix in women has been well managed by cobalt machines, along with applications of intra-vaginal and intra-uterine brachy-RT. Such clinical sites could be managed with telecobalt machines even in the advent of sophisticated linear accelerators. As a renewed challenge, the clinical role and physical characteristics of cobalt-60 (Co-60) teletherapy were evaluated.[6] It was ascertained that MLC addition and tomotherapy will make Co-60 a cost-effective tool for modern image-guided radiotherapy. The efficacy of Co-60-based tomotherapy and 6 MV linac-based tomotherapy plans for head and neck and prostate cancers were investigated using a MIMic binary MLC for the Theratron 780C cobalt machine and Varian Clinac 2100Ex linac, using Monte Carlo Codes.[7] This study showed that the beam fluence and dose–volume histograms (DVHs) showed that both treatment plans achieved the objectives. Recognizing the need for indigenous technology in cobalt machine design, India has pursued developmental efforts since 2005. Panacea Medical Technologies (PMT) Ltd, a Medical Equipment Manufacturer in Karnataka, India, manufactures high-end telecobalt machines and low-energy linear accelerators to support Indian hospitals.[8]

Intensity-modulated radiotherapy (IMRT) and image-guided radiotherapy (IGRT) are presently available in sophisticated linear accelerators. Most efforts on this type of radiotherapy using cobalt equipment were limited to beam modeling and Co-60 tomotherapy models. A prototype MLC model was developed in 2006.[9] It was reported that by using a three-dimensional (3D) treatment planning system (TPS) networked to a commercial styrofoam block and compensator cutters, physical intensity modulation could be achieved by using compensators in cobalt treatment plans to explore IMRT clinical applications. Conformal and IMRT plans of telecobalt developed using physical compensators were comparable to 6/10 MV linear accelerator plans.[10] This study proposed that if cobalt machines have MLC features built in, they can provide considerable benefits in clinical applications. Schreiner *et al.*[11] proposed applying conformal radiotherapy with a conventional cobalt machine using a Tomotherapy benchtop apparatus. Further research using 3D-printed, reusable tungsten bead-filled compensators showed dosimetric outcomes and sparing of organs at risk comparable to 6 MV linac-based IMRT.[12] This provided confidence for the clinical applications of cobalt machine-based IMRT and led to the commissioning and dosimetric validation of compensator-based Co-60 IMRT.[13] IMRT was performed on a ViewRay machine using three cobalt sources with a 120° angulated step-and-shoot method.[14,15] A double-focused MLC was available with each beam orientation. In patient-specific quality assurance (QA), conformal dose distributions for 34 patients showed good dose agreement. Dose coverage and conformity were comparable to the conventional linac IMRT.

Research related to attaching MLC to cobalt machines continued in India during 2006–2016.[16,17] To provide the benefits of IMRT, a 2.9 million USD project was sanctioned under the leadership of Prof. Eric Ford of the University of Washington, Seattle, USA. PMT is the manufacturing partner from India, and Paterson Cancer Center, Chennai, is the clinical partner; the National Cancer Institute approved this project for five years (2017–2022). Because it is less QA intensive, less time-consuming, and less expensive, physical compensator-based IMRT technology was considered.[18] A prototype cobalt machine with provision for mounting physical attenuators in a special tray is under production in the PMT factory, Malur. Some reports highlighted the relevance of forward-planned IMRT—multiple fields on a single isocentre—with different percentage loading and segmental inputs.[19–21] This is commonly known as "poor man's IMRT," using MLCs alone with forward-planned optimization. This highlights the importance of MLCs in providing acceptable plans in 3D conformal radiotherapy (CRT) with multiple fields through forward planning alone, using cobalt beam quality. Another report showed that 3D CRT cobalt treatment plans produced DVH curves comparable to 6 MV plans, highlighting the utility of telecobalt with built-in MLCs.[22]

In IMRT delivery, consecutive leaf-setting sequences deliver the intensity patterns. An illustration shows the required monitor units and exposure time for the selected gantry angle, cumulated to deliver the same IMRT intensity pattern.[23] For six selected gantry angles, the static IMRT algorithm delivered the prescribed dose by 118 segments and 491 total monitor units in 2.57 min; the dynamic slit window method took 189 segments and 621 total monitor units in 3.47 min. This example showed that both static and dynamic IMRT deliver the same total radiation fluence as planned. Because the cobalt source provides a fixed dose rate at MLC apertures/selected beamlets, rather than monitor units, the software calculates the time required for each segment based on inverse planning.

Research and development efforts led to the manufacture of high-accuracy model O-ring Bhabhatron 3i (Bh 3i) model telecobalt machines,[24,25] as the next generation of Bhabhatron II non-MLC version. Three Bh 3i machines have been installed, and two more are in production. Bh 3i has X-ray image guidance, a 6D special couch, a fixed source position with high-speed pneumatic shutters, a moving X diaphragm and additional collimator shutters synchronized with a multi-leaf X collimator, and computerized MLC vane movements with high precision. Provision of programmed, controlled source operations, collimator movements, MLC operations, and routine calibration of MLC vane coordinates, enabling multiple field uploads from the TPS.

An over-travel of 6.25cm, a precise tongue-and-groove MLC design, and accurate variable high-speed movements make both static IMRT and dynamic IMRT feasible. Bh 3i is, therefore, capable of delivering precise, conformal, image guidance-based 3D CRT, field-in-field (FIF) IMRT, mixing of FIF multiple fields, and ARC plans.[21,22] Good homogeneity in treated volumes, along with superior sparing of normal tissues and online image guidance, make O-Ring Bh 3i a unique, high-end model telecobalt, similar to a low-energy linac. The machine's capability to deliver static and dynamic IMRT with MLC slit movements at various speeds is repeatedly verified using automatically programmed stationary settings/leaf sequences saved on an information management system. By feeding Excel sheet data into the central server station, IMRT delivery capability in Bh 3i was tested in the factory and at the user clinics during installation.

Due to the intricate nature of this scientific problem, algorithms are not readily available. No indigenous manufacturers of commercial TPS exist in India. PMT could not secure a permanent license arrangement with TPS manufacturer M/s Prowess Ltd, an American firm. Therefore, we were unable to benefit from the Bh 3i for inverse-planned clinical IMRT executions. In these circumstances, we highlighted radiation delivery using test plans obtained under a temporary license from M/s Prowess, USA. This report highlights the capability of the new Bh 3i in delivering cobalt-based inverse-planned (IP)-IMRT.

2. Materials and methods

2.1. Design

The design of the high-end Bh 3i machine was outlined in a previous study.[21] The source ON–OFF shutters operate with high reliability, with no measurable time lag during system evaluation. A microprocessor-controlled automatic shutter mechanism enables remote sensing of malfunctions. MLCs replace X rectangular diaphragm leaves, 28 pairs of tungsten, each 7.5 cm high. Y diaphragms are moving tungsten blocks, a non-MLC secondary collimator pair. Because of the secondary MLC (28 pairs of moving slits with DC motors) and reduced source-to-skin distance of 80 cm, the maximum field opening for clinical use is 25 cm × 25 cm, with Bh 3i. Figure 1 shows the geometry of the collimators, MLC vanes, and shutter mechanism relative to the fixed source position. Most earlier commercial telecobalt models have longitudinal source-movement mechanisms, adding up to 1 mm of source-position inaccuracy. The new design incorporated a fixed Co-60 source position and an O-ring gantry isocenter to achieve perfect treatment delivery with image guidance. Table 1 compares various technical parameters of Bh 3i with the TrueBeam SVC linac. It was also noted earlier that the Bh 3i used the same circular gantry rim of 100 cm FSD for accurate IMRT delivery.[21] The machine is designed to deliver IMRT and VMAT by incorporating high-end treatment planning software into the existing DosiSoft TPS.

2.2. Evaluation

The main features for the delivery of radiation beamlets are: required attenuation and reproducibility of MLC leaves, permitted inter-leaf leakage, and output factors from minimum × minimum collimator openings up to a 25 cm × 25 cm field. To execute dynamic IMRT, dosimeter readings were measured for various slit sizes at different speeds. These were carried out in Bh 3i at a user site. Similar dynamic measurements were carried out in the TrueBeam SVC model high-energy linac for necessary comparison. At our hospital in Silchar, a TrueBeam SVC model Varian linac was commissioned earlier and can deliver dynamic IMRT and VMAT treatment plans. During commissioning, we performed many dosimetric measurements on this high-energy linac. Dosimetric leaf gap (DLG) estimates

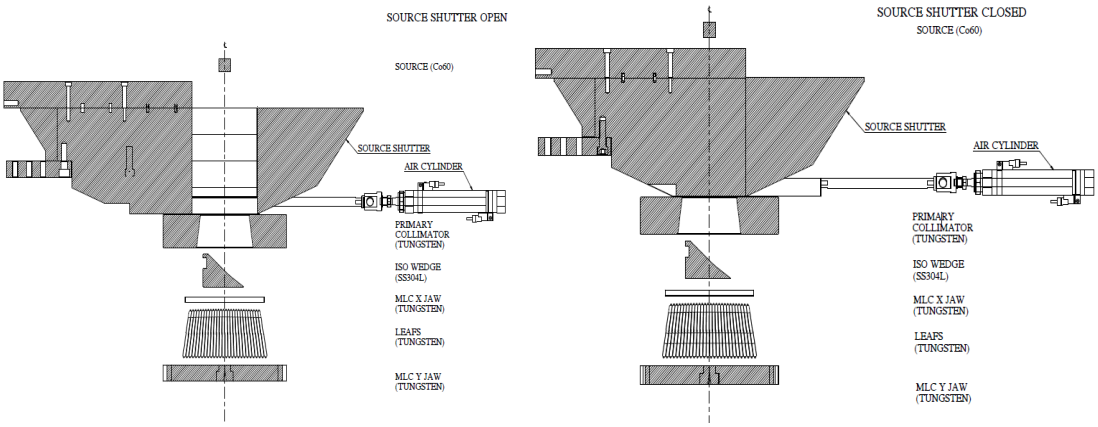

Figure 1. Block diagram of shutter and multileaf collimator (MLC) mechanisms in Bhabhatron 3i

Table 1. Comparison of machines: Bhabhatron 3i cobalt and TrueBeam 6 MV X-rays

No.	Parameters compared	Bhabhatron 3i (Co-60)	TrueBeam SVC (6 MV)
1	Emission source	Cobalt -60 radioactive	Metal target/anode
2	Source size (emission)	15 mm/20 mm diameter	About 3 mm diameter
3	Source stationary	Stationary Co-60 + shutter	Stationary
4	Mean energy (emission)	1.25 MeV (1.17,1.33 MeV)	1.7 MeV (FF) 1.2 MeV (FFF)
5	Machine design	O-ring type, fixed source	Pendulum with Portal Vision
6	Image guidance	Orthogonal kV imaging	kV imaging/MV imaging
7	Iso-center distance	80 cm	100 cm
8	Iso-center uncertainty	0.23mm (measured)	1.0 mm (measured)
9	Maximum radiation field	25 cm × 25 cm (10 mm MLC)	20 cm (5 mm) 40 cm (10 mm MLC)
10	Design MLC assembly	At X-collimator (upper jaws)	Tertiary below X- and Y- collimators
11	Diaphragm transmission	Maximum 0.36% (measured)	Maximum 0.36% (measured)
12	MLC width at isocenter	10 mm resolution	5 mm (till 20 cm) 10 mm (20–40 cm)
13	MLC leakage (%)	Maximum 0.04% (measured)	Maximum 1.00% (measured)
14	Penumbra at maximum dose	9.8 mm (Y-jaw) 11.1 mm (X-jaw)	5.2 mm (cross) 5.5 mm (in)
15	Dose rate at treating distance	200–300 cGy/min (decaying)	300–600 cGy/min
16	Incorporated automation	Microprocessor controlled	Microprocessor controlled
17	Beam stopper	Default as counterweight arm	C-arm with portal imaging arm
18	%depth dose-10 cm 10 × 10	54.0%	66.9%

Abbreviations: FF: Flattening filter; FFF: Flattening filter-free; MLC: Multileaf collimator.

were performed with an ion chamber dosimeter, kept at a depth of 5 cm in a water phantom. Measurements were carried out at 80cm and 100 cm source-to-chamber distances, for Bh 3i and linac, respectively. At the outset, it was emphasized that comparing the cobalt machine with a high-energy linac is intended to demonstrate mechanical and dosimetric feasibility rather than clinical equivalence. By forward-planned FIF IMRT, we found that treatment plans developed by segmental overlap of multiple fields could be safely delivered. Inversely planned IMRT plans were checked using the American Association of Physicists in Medicine Task Group 119 (TG 119) test patient contours and images.[26] Figure 2 highlights the IMRT planning and execution process sequences.

2.3. Implementation of inverse planned intensity-modulated radiotherapy capability in Bhabhatron 3i

2.3.1. Quality assurance

Our QA tests on delivering multi-segmental fields of dynamic IMRT and variable-speed dynamic IMRT showed the feasibility of dose delivery with Bh 3i. We tested this separately at the site and during commissioning many times, and we have preserved the documentation.

2.3.2. Commissioning of Bhabhatron 3i for inverse planned intensity-modulated radiotherapy

As indicated in a previous study, the presently available TPS (DosiSoft, France) does not support inverse planning capability for the cobalt beam.[24] This, however, supports digital imaging and communications in medicine data for computed tomography (CT) image transfer and is capable of setting up multiple irregular MLC fields in any angulation, as well as multiple irregular fields overlapped together in a particular gantry orientation. For parameterization and testing, we obtained a temporary license from M/S Prowess TPS, USA. A beam library was created at the principals in the USA (for testing purposes only) by sending measured parameters of the Bh 3i, already installed and used for clinical applications. This TPS uses the Collapsed Cone Convolution Superposition algorithm, which is identical to those used clinically. Exported plans do not require any further manual modification. In the future, the same TPS can be used for clinical implementation. Radiation beam profiles of Bh 3i were measured at 80 cm source-to-skin distances at recommended depths (in-line, cross-line, diagonals) for 3 × 3 cm^2 to 25 × 25 cm^2 field sizes. Output factors were measured for square and rectangular fields (minimum to maximum) at 80 cm source-to-axis distances, with a 0.125 ionization chamber, at 5 cm depth. All measurements were performed using the Radiation Field Analyzer and a water phantom.

2.3.3. Treatment plans generated for intensity-modulated radiotherapy and verification of radiation fluences

The IMRT planning and phantom QA were based on four standard TG 119 test cases: Head and neck, prostate, multi-structure, and C-shape. IMRT plans were created in the Prowess TPS (Prowess Inc., USA) to evaluate the planning and delivery performance of the Bh 3i cobalt machine under different clinical conditions. All plans were normalized to meet the clinical goals defined in TG 119, ensuring target coverage and sparing of organs at risk. Each plan was designed using the dynamic MLC technique, which allows precise beam shaping to deliver accurate doses to the tumor

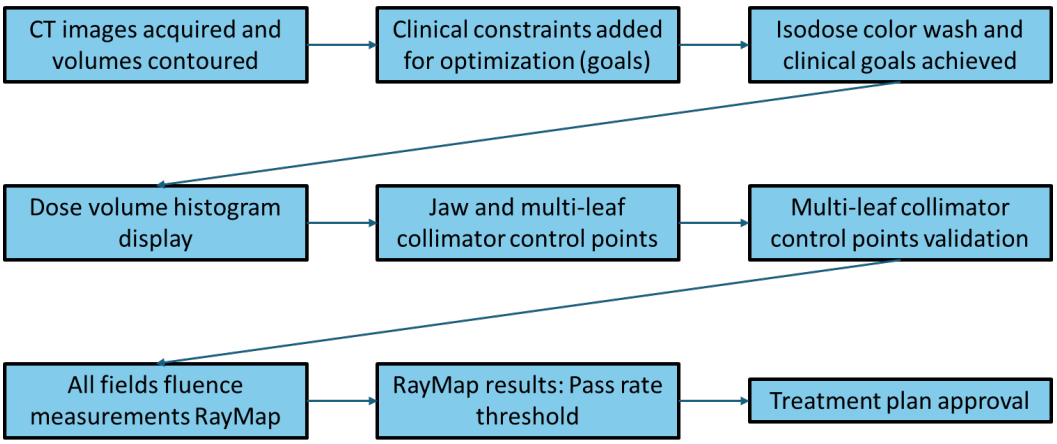

Figure 2. IMRT process workflow sequences
Abbreviations: CT: Computed tomography; IMRT: Intensity-modulated radiotherapy.

while protecting healthy tissues. To further evaluate the quality of each plan, we assessed two important metrics: the conformity index and homogeneity index.

The IMRT treatments were planned using X-ray CT images. These test plans have 1 cm resolution (as specified by MLC in Bh 3i). For verification of accuracy in delivery of these plans in the machine, a solid phantom (solid water, 357 mm × 81 mm × 320 mm dimensions) was scanned in the CT machine by keeping the array detector two-dimensional (2D) map matrix/RayMap (Guangzhou RayDose Medical Technology Co., Ltd., China) at the desired depth. It contains a 2D map matrix with a parallel-plate ion chamber and 1,261 detectors, providing high resolution. Figure 3 shows the 2D Map Matrix phantom kept on the patient support assembly (PSA) during setup for QA.

RayMap has a sensitivity of 3.6 nC/Gy at an operating bias of 300 V. The machine exposed all IMRT fields as pre-treatment QA, as per the TPS plans, at 0° gantry orientation, as per recommendations in the TG 119 protocol. Resultant TPS-generated radiation fluence patterns were compared with the measured fluence using separate RayMap software. Gamma index analysis was conducted using a global gamma criterion of 3% dose difference and 3 mm distance-to-agreement. A passing threshold of ≥95% was applied, in accordance with the recommendations of TG 119. A gamma pass rate of ≥95% was used as the acceptance threshold, confirming that our system delivers treatment plans with high precision and reliability, in line with clinical safety standards. Agreement between exposed fluence in a plane and planned TPS delivery, based on well-accepted gamma values, validates correct execution of treatment plans.

3. Results

The output factors measured for Bh 3i are shown in Table 2. Reproducibility of leaf positions of MLC is shown in Table 3. The leakages measured in different orientations of the gantry are highlighted in Table 4. These values were compared against the 6 MV beam of the TrueBeam linac. Bh 3i MLC leakages were much lower than linac MLCs. When the slit field by MLC was moved at constant velocity, the integrated output at 5 cm depth for different slit openings is highlighted in Table 5. DLG measurements of Bh 3i showed identical trends with 6 MV (flattening filter [FF], flattening filter-free [FFF]), 10 MV (FF, FFF), and 15 MV beams of the linac. DLG values were 1.08 mm for Bh 3i, compared to 1.06 mm (6 MV-FF), 0.90 mm (6 MV-FFF), 1.21 mm (10 MV-FF), 1.10 mm (10 MV-FFF), and 1.24 mm (15 MV-FF), respectively. It can be seen that the Bh 3i integrated charge for each slit width showed a higher magnitude, possibly due to the shorter SSD of 80 cm compared to 100 cm for the linac. It was observed that the larger magnitude theoretical penumbra of the cobalt source in the conventional beam does not appear to show any effect in our measurements in moving multi-leaf slits (at X-collimator) in dynamic IMRT delivery. With forward planning, five pairs of opposing fields with Bh 3i in the head and neck contour made it possible to prepare multiple segmented treatment plans to reduce hot spots, as encountered in head and neck opposed, open single-pair fields (Figure 4).

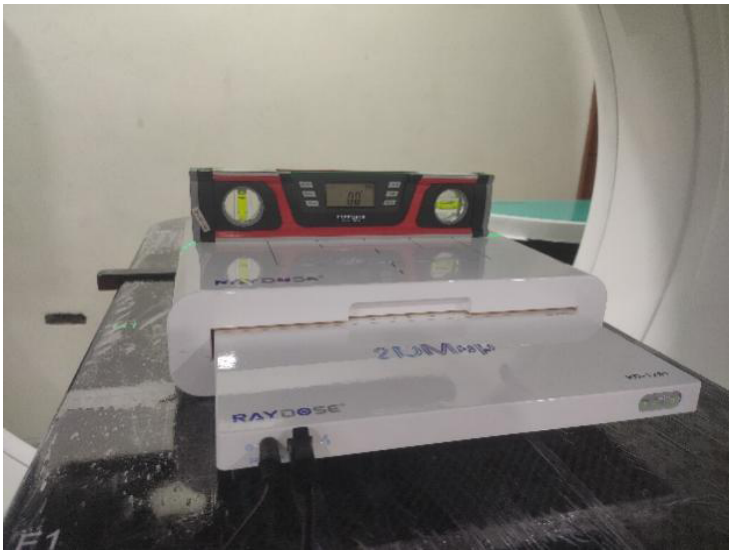

Figure 3. Array detector (two-dimensional map matrix/RayMap) kept in the O-ring gantry for quality assurance measurements

Table 2. Normalized output factors Bhabhatron 3i (80 cm SSD, 5 cm depth in water)

Field type	Field size (cm²)	OPF
Square		
1	3 × 3	0.754
2	4 × 4	0.849
3	5 × 5	0.859
4	6 × 6	0.921
5	8 × 8	0.959
6	10 × 10	1.000
7	12 × 12	1.027
8	15 × 15	1.058
9	20 × 20	1.096
10	25 × 25	1.112
Rectangle		
1	5 × 10	0.927
2	10 × 10	1.000
3	15 × 10	1.031
4	20 × 10	1.040
5	25 × 10	1.045
6	10 × 15	1.020
7	10 × 20	1.032
8	10 × 25	1.037
9	–	–
10	–	–

Abbreviations: OPF: Open-photon field; SSD: Source-to-skin distance.

Table 3. Accuracy of multileaf collimator leaf settings

No.	Head orientation	Measured accuracy with Dial Gauge method (mm)
1	0°	−0.05 ± 0.03 (n = 6)
2	90°	−0.04 ± 0.01 (n = 6)
3	270°	−0.05 ± 0.01 (n = 6)

Table 4. MLC leakages measured in Bhabhatron 3i and TrueBeam 6 MV (FF)

Equipment	MLC leakage	
	Head at 90°	Head at 0°
Bhabhatron 3i cobalt machine	0.004(0.40%)	0.004(0.40%)
TrueBeam Linac 6 MV (FF)	0.0139 (1.39%)	0.0131(1.31%)

Abbreviations: FF: Flattening filter; MLC: Multileaf collimator.

Table 6 highlights the dose constraints for various structures and the actual dose delivered per TPS plans by Bh 3i, showing the capability of Bh 3i-configured beam and MLC segments to achieve the planned doses accurately. Table 6 shows that 5% of the dose constraint could not be achieved. Because the target was complex and the volume was small, only this much dose optimization was achieved. All other planners' goals were achieved. Table 7 shows the same TG 119 test plans achieved by the TrueBeam Varian linac, using the Eclipse TPS workstation. The achieved IMRT plans in TrueBeam dose delivery and Bhabhatron 3i dose delivery are comparable (Tables 6 and 7). For corresponding volumes, absolute doses vary slightly because of 10 mm and 5 mm MLC resolution differences, scatter quality variations, MLC leakage variations, and divergence variations at 80 cm and 100 cm source distances, but the results show compliance of telecobalt MLC IMRT using TG 119 test plans. The TPS-planned dynamic IMRT plan of head and neck Bh 3i treatment, at a selected slice section, is shown in Figure 5. Figure 6 illustrates the corresponding DVH and the collimator MLC settings generated for optimum fluence dose delivery for this plan. The achieved conformity and homogeneity in the volumes of interest are also displayed in Figure 6. Figure 7 shows dose distribution test fluences for head and neck and prostate plans, indicating calculated gamma values within acceptable limits (3 mm and 3%). Similar results were obtained for other sites as well. For example, the RayMap-measured radiation fluence statistics for head and neck are: dose points 1,261; analyzed points 284; pass points 273; fail points 11; pass rate 96.13%, with a standard deviation of 0.37%. The planned point doses were 369.08 cGy at the maximum point and 286.66 cGy at the center point, whereas the measured point doses were 363.01 cGy at the maximum point and 285.16 cGy at the center point, respectively.

4. Discussion

This report demonstrated that the Indian-manufactured Bh 3i machine can deliver IP-IMRT. The data in this script

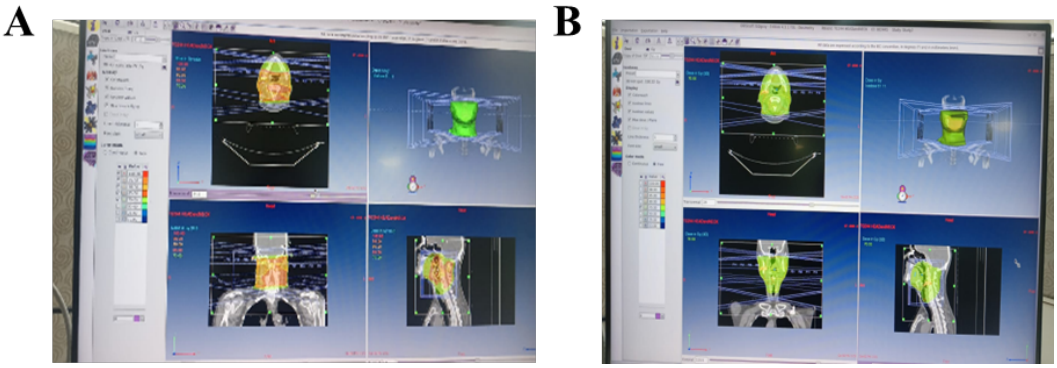

Figure 4. Effect of multiple stationary segmental fields. (A) Head and neck Co-60 parallel opposed fields (uncompensated) with hot spots (neck). (B) Head and neck Co-60 with multileaf collimator multiple segmented fields (field-infield, five pairs) homogeneous dose.

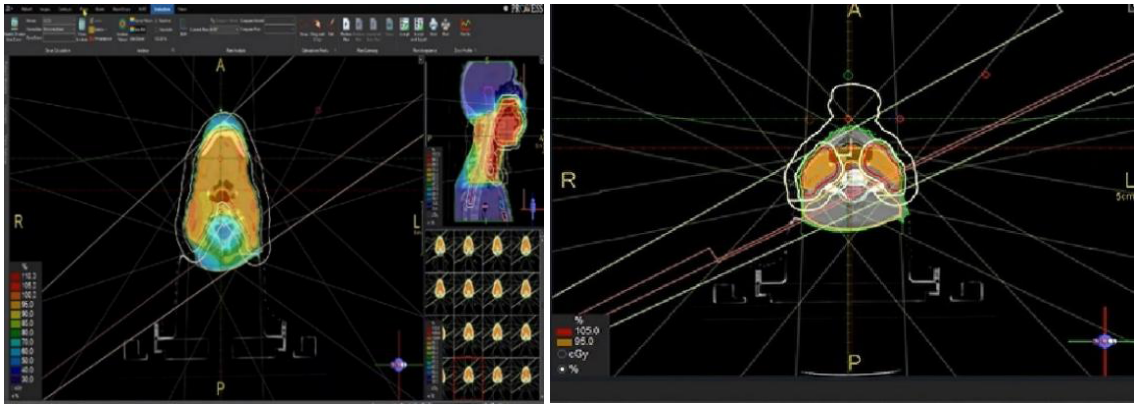

Figure 5. Dynamic intensity-modulated radiotherapy plan for head and neck treatment using Bhabhatron 3i cobalt machine

Table 5. Comparison of output integrated for slit width moved at constant velocity

No.	Slit width (mm)	Bhabhatron 3i cobalt machine		TrueBeam Linac 6 MV (FF)	
		Integrated nC at 90°	Integrated nC at 0°	Integrated nC at 90°	Integrated nC at 0°
1	2	0.158	0.140	0.136	0.135
2	4	0.235	0.205	0.193	0.194
3	6	0.313	0.303	0.248	0.250
4	8	0.390	0.375	–	–
5	10	0.454	0.451	0.364	0.366
6	12	0.543	0.530	–	–
7	14	0.621	0.608	0.479	0.481
8	16	0.698	0.685	0.537	0.538
9	18	0.793	0.764	–	–
10	20	0.871	0.844	0.652	0.654

Abbreviation: FF: Flattening filter.

Table 6. Optimized dose delivery by dynamic IMRT in Bhabhatron 3i treatment in test cases

S. No.	Test case	Structure	TPS-planned Bhabhatron 3i IMRT		
			Desired planner's goal		Dynamic IMRT (TPS) dose
	TG 119 cases		Volume	Dose	
1	Head and neck	PTV	90% volume	≥50.0 Gy	51.28 Gy
			99% volume	≥46.5 Gy	46.49 Gy
			≤20% volume	>50.0 Gy	53.72 Gy
		Spinal cord	No part of vol.	>40.0 Gy	38.01 Gy
		Parotid gland (left)	50% volume	<20.0 Gy	19.82 Gy
		Parotid gland (right)	50% volume	<20.0 Gy	19.93 Gy
2	Prostate	PTV	95% volume	≥75.6 Gy	75.86 Gy
			5% volume	≥83.0 Gy	80.91 Gy
		Rectum	30% volume	≤70.0 Gy	46.39 Gy
			10% volume	≤75.0 Gy	62.41 Gy
		Bladder	30% volume	≤70.0 Gy	59.53 Gy
			10% volume	≤75.0 Gy	73.03 Gy
3	Multi-structure	Central target	99% volume	≥50.0 Gy	50.00 Gy
			10% volume	≤53.0 Gy	52.60 Gy
		Superior part of the target	99% volume	≥25.0 Gy	26.94 Gy
			10% volume	≤35.0 Gy	33.97 Gy
		Inferior part of the target	99% volume	≥12.5 Gy	14.97 Gy
			10% volume	≤25.0 Gy	22.73 Gy
4	C-shape area	PTV	95% volume	≥50.0 Gy	50.00 Gy
			10% volume	≤55.0 Gy	54.75 Gy
		Core	5% volume	≤25.0 Gy	30.95 Gy

Abbreviations: IMRT: Intensity-modulated radiotherapy; PTV: Planning target volume; TPS: Treatment planning system.

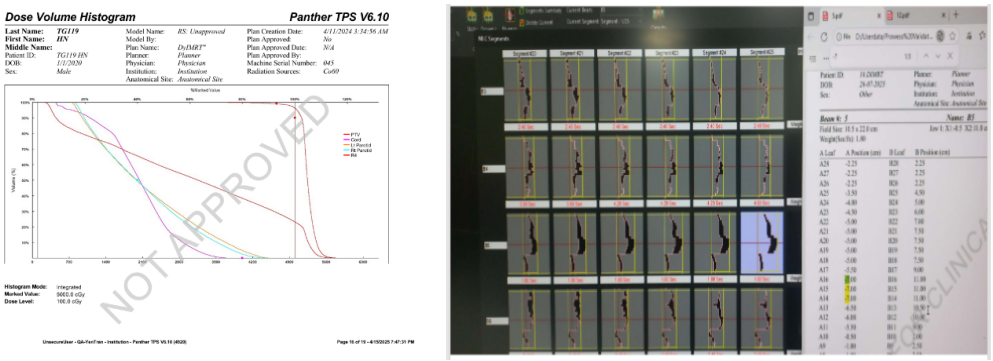

Figure 6. Illustration of dose–volume histogram and different segmental fields during dynamic window delivery

Table 7. Optimized dose delivery by dynamic IMRT in TrueBeam treatment plans

S. No.	Test case	Structure	Eclipse TPS-planned TrueBeam IMRT		
	TG 119 cases		Desired planner's goal		Dynamic IMRT (TPS) dose
			Volume	Dose	
1	Head and neck	PTV	90% volume	≥50.0 Gy	51.52 Gy
			99% volume	≥46.5 Gy	49.83 Gy
			≤20% volume	>50.0 Gy	53.08 Gy
		Spinal cord	No part of vol.	>40.0 Gy	39.38Gy
		Parotid gland (left)	50% volume	<20.0 Gy	18.78 Gy
		Parotid gland (right)	50% volume	<20.0 Gy	18.93 Gy
2	Prostate	PTV	95% volume	≥75.6 Gy	77.04 Gy
			5% volume	≥83.0 Gy	81.07 Gy
		Rectum	30% volume	≤70.0 Gy	53.32 Gy
			10% volume	≤75.0 Gy	72.93 Gy
		Bladder	30% volume	≤70.0 Gy	24.48 Gy
			10% volume	≤75.0 Gy	48.04 Gy
3	Multi-structure	Central target	99% volume	≥50.0 Gy	50.38 Gy
			10% volume	≤53.0 Gy	52.55 Gy
		Superior part of the target	99% volume	≥25.0 Gy	25.50 Gy
			10% volume	≤35.0 Gy	33.07 Gy
		Inferior part of the target	99% volume	≥12.5 Gy	13.08 Gy
			10% volume	≤25.0 Gy	23.83 Gy
4	C-shape area	PTV	95% volume	≥50.0 Gy	50.04 Gy
			10% volume	≤55.0 Gy	54.90 Gy
		Core	5% volume	≤25.0 Gy	15.10 Gy

Abbreviations: IMRT: Intensity-modulated radiotherapy; PTV: Planning target volume; TPS: Treatment planning system.

are compiled to highlight a pre-clinical technical validation rather than clinical implementation. Comparing our dosimetric data and achieved dose coverage for test plans with the TrueBeam linac is more of an academic exercise to validate the Bh 3i beam; it was not intended to demonstrate mechanical and dosimetric feasibility, but rather clinical equivalence. In addition, we did not use TrueBeam data in Prowess TPS to compare both plans from the same TPS. Currently, the literature contains no reports on the clinical application of Inversely Planned IMRT in any other commercially available cobalt machines. We earlier highlighted that Bh 3i is an O-ring type with image guidance, having the X-collimator (near to the source plane) replaced by MLC vanes, along with a safety sliding thick collimator.[24,25] The delivery of IMRT with Bh 3i is safer than an add-on MLC attachment executing IMRT with other commercial manufacturers, where they may not have integration with the main rectangular collimators. The O-ring structure ensures high accuracy at the isocenter; therefore, IMRT delivery is comparable to well–tested linear accelerator designs. Table 2 shows no sagging of MLC leaves, which is required for safe delivery of isocentric IMRT. Currently, FIF-IMRT is available in Bh 3i, with applications in head and neck as indicated in Fig. 4, and the existing DosiSoft TPS can support these planings.[19-21] Figures 5–7 show that IP-IMRT can be executed with Bh

3i. Table 5 shows that IMRT dose restrictions for different inner contours and the goals are achieved as per planners/radiation oncologist's requirements. Dose-delivery QA also showed gamma pass rates within recommended criteria (±3 mm on coverage isodose and within 3%). Compared with similar TG 119 test plans carried out in Eclipse TPS for 6 MV (Table 6), Bh 3i clearly demonstrates its capability to deliver IP-IMRT.

Therefore, if DosiSoft makes inverse planning software available through licensing, we will be able to use IP-IMRT for clinical applications in Bh 3i. It is strongly emphasized that PMT, as a manufacturer of high-end telecobalt and linear accelerators, should make all collaborative efforts, liaise with TPS manufacturers abroad, and incorporate the IP-IMRT facility with the existing Bh 3i installations to permanently overcome the present issues. Once this bottleneck is overcome, we can organize type approval efforts with the regulatory authority in India for clinical use of Bh 3i for inverse-planned IMRT. In parallel, we should undertake in-house efforts to generate inverse planning optimization incorporated in the existing Dosi Soft TPS. It was mentioned in a previous study that, for research purposes, the PMT firm is manufacturing another Bh 3i to provide "physical intensity modulation" (PIM), which is on a similar objective to provide IMRT benefit with a cobalt machine[18], but it is for a non-MLC O-ring machine, with provision for physical intensity modulation (PIM) molds. But this machine is not yet installed, awaiting clearance formalities with the regulatory authorities in India. The need for optimization of radiotherapy resources in the hospital to continue to use telecobalt machines complementary to the linear accelerator was also stressed in a recent communication mentioning the availability of the latest MLC model telecobalt with treatment plan optimization capabilities.[27]

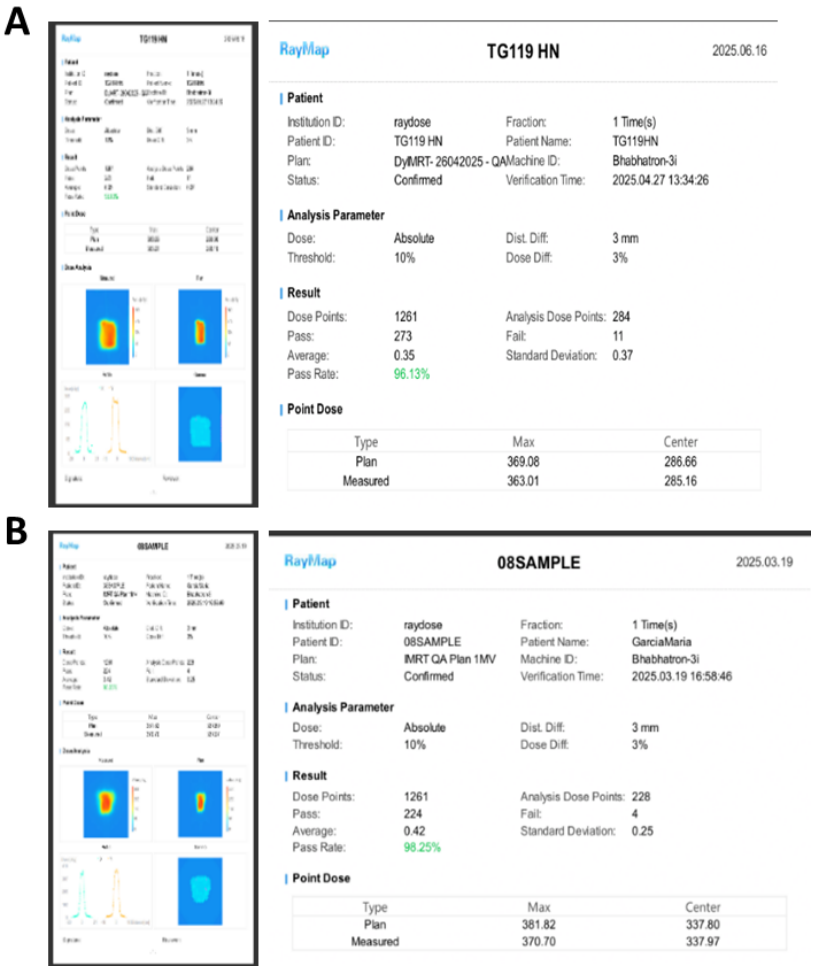

Figure 7. Illustration of fluence patterns with two-dimensional map check phantom measurements for (A) head and neck plan and (B) prostate plans

Acknowledgments

The authors thank the Director, CCHRC, SILCHAR, and CEO, Panacea Medical Technologies Ltd, Malur, Karnataka, for permission to submit data relating to the RT Machine. Our thanks are extended to M/s Vijay Super Speciality Hospital and Cancer Centre, Baisuhalli, Dharmapuri, Tamil Nadu.

Funding

None.

Conflict of interest

The authors declare that there are no competing interests with any agencies, as well as among themselves.

Author contributions

Conceptualization: Ramamoorthy Ravichandran, G.V. Subrahmanyam
Formal analysis: Ramamoorthy Ravichandran
Investigation: Manikandan Palanisamy, Tarani Mondal, Nandhiya Muthuraman
Methodology: Ramamoorthy Ravichandran, Manikandan Palanisamy
Writing–original draft: Ramamoorthy Ravichandran
Writing–review & editing: Ramamoorthy Ravichandran, Manikandan Palanisamy

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

Data are available from the corresponding author upon reasonable request.

References

1. Page BR, Hudson AD, Brown DW, *et al.* Cobalt, linac, or other: What is the best solution for radiotherapy in developing countries? *Int J Radiat Oncol Biol Phys.* 2014;89(3):476-480.

   doi: 10.1016/j.ijrobp.2013.12.022

2. Van Dyk J, Battista JJ, Almond PR. A retrospective of Co-60 radiotherapy: The atom bomb that saves lives. *Med Phys Int J.* 2020;4(Spl Issue. History of Medical Physics):327-350. Accessed September 11, 2026. https://amos3.aapm.org/abstracts/pdf/166-58831-15631646-171798-1721147678.pdf

3. Nagaraj H, Bhudatt Paliwal, *et al.* Debate on clinical efficacy and future projection on applications of telecobalt machine. *J Cancer Res Ther.* 2014;10:781-790.

4. Chu JCH, Coia LR, Aziz D, Stafford PM. Dose to superficial node for patients with head and neck cancer treated with 6 MV and 60Co photons. *Radiother Oncol.* 1991;21(4):257-260.

   doi: 10.1016/0167-8140(91)90050-Q

5. Kannan R, Dutta G, Ravichandran R, *et al.* Feasibility and acute toxicity of seven fractions per week accelerated radiotherapy with or without concurrent chemotherapy in laryngopharyngeal squamous cell carcinoma: A pilot study. *J Head Neck Physicians Surg.* 2026;14(1):86-92.

   doi: 10.4103/jhnps.jhnps_5_26

6. Van Dyk J, Battista JJ. Co-60 an old modality, a renewed challenge. *Curr Oncol.* 1996;3(10):8-17. Accessed September 11, 2026. https://www.researchgate.net/publication/238082452_Cobalt60_An_Old_Modality_A_Renewed_Challenge

7. Joshi C, Dhanesar S, Darko J, Kerr A, Vidyasagar P, Schreiner LJ. Practical and clinical considerations in Co-60 tomotherapy. *J Med Phys.* 2009;34(3):137.

   doi: 10.4103/0971-6203.54847

8. Jayarajan K, Kar DC, Sahu R, Radke MG, Singh M. BARC develops Co-60 teletherapy machine for cancer treatment. *BARC Newsletter.* 2005;253:10-14. Accessed September 11, 2026. https://barc.gov.in/barc_nl/2005/200502.pdf

9. Singh IR, Ravindran PB, Ayyangar KM. Design and development of motorized multileaf collimator for telecobalt unit. *Technol Cancer Res Treat.* 2006;5(6):597-605.

   doi: 10.1177/153303460600500607

10. Adams EJ, Warrington AP. A comparison between cobalt and linear accelerator-based treatment plans for conformal and intensity modulated radiotherapy. *Br J Radiol.* 2008;81(964):304-310.

    doi: 10.1259/bjr/77023750

11. Schreiner LJ, Joshi CP, Darko J, Kerr A, Salomons G, Dhanesar S. The role of Co-60 in modern radiotherapy dose delivery and image guidance. *J Med Phys.* 2009;34(3):133-136.

    doi: 10.4103/0971-6203.54846

12. Macomber MW, Fong N, Sponsellar PA, *et al.* A novel compensator device to deliver IMRT with Co-60 units in low- and middle-income countries: A comparative dosimetric analysis. *Int J Radiat Oncol Biol Phys.* 2017;99(2):S231.

    doi: 10.1016/j.ijrobp.2017.06.567

13. Oh K, Sengupta B, Olanrewaju A, *et al.* Commissioning and dosimetric validation of a novel compensator based

Co-60 IMRT system for evaluating suitability to automated treatment planning. *Med Phys.* 2023;50(7):4466-4479.

doi: 10.1002/mp.16423

14. Li HH, Rodriguez VL, Green OL, *et al.* Patient specific quality assurance for the delivery of (60)Co intensity modulated radiotherapy subject to a 0.35 T lateral magnetic field. *Int J Radiat Oncol Biol Phys.* 2015;91:65-72.

    doi: 10.1016/j.ijrobp.2014.09.008

15. Wooten HO, Rodriguez VL, Green OL, *et al.* Bench mark IMRT evaluation of a Co-60 MRI guided radiotherapy system. *Radiother Oncol.* 2015;114(3):402-405.

    doi: 10.1016/j.radonc.2015.01.015

16. Sahani G, Kumar M, Sharma PD, *et al.* Compliance of Bhabhatron-II telecobalt unit with IEC standard - Radiation safety. *J Appl Clin Med Phys.* 2009;10(2):120-130.

    doi: 10.1120/jacmp.v10i2.2963

17. Sharma SD, Kumar R, Kakade NR, *et al.* Development of a MulriLeaf Collimator for indigenous Telecobalt machine Bhabhatron-II. In: Proceedings of the 37th Annual Conference of Association of Medical Physicists of India. Hyderabad, India; 2016:I-07:8-9.

18. Govinda Rajan KN. Project introduction and a compensator based IMRT for cobalt. *J Med Phys.* 2017;42(suppl 1):21. Accessed September 11, 2026. https://ampi.org.in/wp-content/uploads/2018/10/2017-JMP-Suplement-AMPICON2017.pdf

19. IMRT Treatment Planning-Forward Planning. In: Van Dyk J, ed. *The Modern Technology of Radiation Oncology.* Vol 2. Madison, Wisconsin, USA: Medical Physics Publishing; 1999. Chapter 6, page 223.

20. Murthy KK, Sivakumar SS, Davis CA, Ravichandran R, El Ghamrawy K. Optimization of dose distribution with multi-leaf collimator using field-in-field technique for parallel opposing tangential beams of breast cancers. *J Med Phys.* 2008;33(2):60-63.

    doi: 10.4103/0971-6203.41194

21. Al-Rahbi ZS, Al Mandhari Z, Ravichandran R, *et al.* Dosimetric comparison of intensity modulated radiotherapy isocentric field plans and field in field (FIF) forward plans in the treatment of breast cancer. *J Med Phys.* 2013;38(1):22-29.

    doi: 10.4103/0971-6203.106601

22. Rani AR, Ayyangar K, Reddy AR, Kumar AA, Reddy PRY. Efficacy of MLC based Co-60 plans: A DVH comparison and analysis with 6 MV plans. *Med Dosim.* 2021;46(1):80-85.

    doi: 10.1016/j.meddos.2020.09.002

23. Intensity Modulation Methods. In: Van Dyk J, ed. *Beam Shaping and Intensity Modulation. The Modern Technology of Radiation Oncology.* Madison, Wisconsin, USA: Medical Physics Publishing; 1999;Chapter 12:466-472.

24. Ravichandran R, Bonanthaya RK, Mani T, *et al.* A new model O Ring isocentric telecobalt machine with built in imaging system and multi-leaf beam collimation. *Int J Radiol Radiat Ther.* 2024;11(5):129-135.

    doi: 10.15406/ijrrt.2024.11.00400

25. Ravichandran R, Subrahmanyam GV. An Elite Version of Telecobalt Machine with O-ring Design for Clinical Radiotherapy. *J Med Phys.* 2024;49(4):719-720.

    doi: 10.4103/jmp.jmp_164_24

26. Ezzell GA, Burmeister JW, Dogan N, *et al.* IMRT commissioning: multiple institution planning and dosimetry comparisons, a report from AAPM Task Group 119. *Med Phys.* 2009;36(11):5359-5373.

    doi: 10.1118/1.3238104

27. Ravichandran R. Optimization of radiotherapy resources in cancer treatments: Issues relating to cobalt treatments in Indian Context. *Int J Radiol Radiat Ther.* 2026;13(2):58-62.

    doi: 10.15406/ijrrt.2026.13.00455