New-generation Indian Linear Accelerator: Validation of Specifications and Comparative Analysis

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Abstract

Introduction: Radiotherapy (RT) plays a crucial role in cancer treatment, with two-thirds of patients receiving external-beam radiation therapy (EBRT). In India, the growing cancer burden necessitates a significant expansion of RT infrastructure. The current estimates indicate a severe shortfall, with only 0.6 RT machines per million people, far below international recommendations. To bridge this gap, India has focused on developing indigenous linear accelerators under the "Make in India" initiative. In the recent past, a low energy model linear accelerator is designed and manufactured in India and are being installed in different oncology centers. The performance specifications are reviewed and compared with well tested imported model to assess the efficacy in terms of radiation delivery parameters. **Materials and Methods:** A low-energy linear accelerator (6 MV), magnetron radiofrequency-powered model, Siddharth II©, is manufactured by M/s Panacea Medical Technologies Pvt Ltd., India, as an indigenous venture. This O-ring structure includes a Kilo-voltage imaging facility and tertiary multi-leaf collimators for image-guided intensity-modulated and volumetric arc radiation therapy. Measured data on the machine's performance, beam characteristics, and radiation safety parameters during commissioning and type approval of five such linacs are summarized. In addition, an attempt has been made to compare the efficacy of this model with the measured 6 MV photon values of the imported TrueBeam© model from M/s Varian AG, USA. **Results:** The performance evaluation of five linear accelerators installed over the past 2 years, along with measured radiation data, confirms that the 6 MV linac has an adequate design, delivering radiation beams comparable to well-tested imported models widely used in India. Additionally, all radiation safety parameters of the Siddharth II© linac are on par with those of imported machines. **Conclusion:** The results demonstrate that the Siddharth II© linac meets clinical requirements and compares favorably with imported models. The successful implementation of this technology marks a significant step toward self-reliance in cancer treatment infrastructure, ensuring wider accessibility and affordability for Indian patients.

Keywords: Low-energy linac, multileaf collimator, radiotherapy machines, Siddharth II©

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Introduction

Radiotherapy (RT) is an important modality in the treatment of cancer, with approximately two-thirds of patients receiving external-beam radiation therapy (EBRT) either as a standalone treatment or in combination with other modalities.[1] As the global incidence of cancer increases, so does the demand for effective RT services. In India, there is a significant need to augment the existing RT infrastructure to meet the rising demand for cancer treatment. International recommendations indicate,[2] at a rate of cancer incidence 500–2500 per 1 million population in low- and middle-income countries, there is a need for 1–3 megavoltage teletherapy EBRT machines per million population, to ensure satisfactory care.

In response to this pressing need, India is focusing on enhancing its radiotherapy machine (RTM) infrastructure. A recent report[3] analyzed the country's RT machine infrastructure, its geographical distribution, and the projected need for further augmentation of RT facilities. The report highlighted that there are 823 RTMs in 554 clinics, with an average of 1.5 RTMs per institute. Notably, 69.4% of these centers have only one RTM. The overall availability stands at just 0.6 RTMs per million

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population, with a shortfall of 1,209 RTMs. In addition, there is a significant disparity in regional distribution, ranging from 0.08 RTMs per million to 2.94 RTMs per million. The Northern region requires approximately 480 additional RTMs, while the large state of Uttar Pradesh alone needs 279. The COVID-19 pandemic negatively impacted the national RTM growth rate, which declined from 5% to 1.9% in 2020–2021. Therefore, there is an urgent need to significantly augment the number of EBRT machines in India.

In the year 2009, Ravichandran[4] in an analysis of various parameters of Telecobalt, 6 MV and 15 MV/18MV radiation beams, made an objective recommendation that the use of cobalt radiation therapy machines shall be continued for simple treatments and cost-effective cure and palliation. A low-energy (LE) linac could be used additionally, for treatments of conformal three-dimensional conformal radiotherapy (3D CRT) and intensity-modulated radiation therapy (IMRT) for more optimized treatment plans. This recommendation was based on the experience over the five decades, that in leading RT centers using high end Klystron powered linacs (with 15–18 MV and 22 MeV electron beams), about 70% of the patients are treated with only 6 MV photons. Moreover, about 60% of the patients are treated by 3D-CRT simple plans only, with multi-leaf collimator (MLC) fields.

In India, the Government has promoted indigenous ventures under the "Make in India" initiative, aligning with the self-reliance objective (Atma Nirbhar Bharat, Government of India) across various sectors. As an extension of this philosophy, there is a need to develop linear accelerator technology as an entrepreneurial effort to make the latest advancements more accessible and affordable in the Indian currency.

Research and development (R and D) efforts related to the design of external-beam radiotherapy (EBRT) machines, including telecobalt and linear accelerators, have been ongoing at M/s Panacea Medical Technologies Ltd. (PMT) in Malur, Karnataka. These efforts began in 2005 for telecobalt machines and after 2013 for linear accelerators. Recently, a LE linear accelerator has been designed and manufactured in India, incorporating a magnetron power source, a radiofrequency (RF) standing waveguide structure, and a MLC assembly. Furthermore, a precise integration of MLCs in O-ring-type Indian-made telecobalt machines, replacing the traditional X Jaw collimator with MLC, has also been carried out.[5,6]

This report focuses on the installation and evaluation of the Siddharth II© LE linear accelerators (Linacs), a step toward addressing the increasing demand for RT in India. A review of the beam parameters assessed by the radiation field analyzer (RFA) to validate the basic specifications and performance capabilities of the five Siddharth II© LE linacs installed over the past 2 years is made. Comparison is carried out in similar lines with an earlier work,[7] in terms of the design aspects against well tested imported model, to assess the adequacy and efficacy in terms of radiation delivery parameters. These five machines have been type-approved and licensed for clinical use by the national regulatory authority, Atomic Energy Regulatory Board (AERB), Government of India.

Materials and Methods

Design and specifications of linear accelerator

The newly designed Siddharth II© model 6 MV linear accelerator is manufactured by M/s PMT. This is an "O-ring model" equipped with a domestically developed magnetron RF power source and a standing wave accelerator tube, both designed and fabricated at their manufacturing premises.[8] The model has received US FDA approval for medical applications.[9]

During 2022–2023, five LE Linacs were manufactured, type-approved, and licensed for medical use; two machines in 2023 and three more in 2024 to date. In India, the AERB is responsible for licensing these machines for clinical use under its safety code.[10] The Siddharth-II model is compliant with applicable International Electrotechnical Commission (IEC) standards. The machine head is mounted on a ring-type gantry to achieve the highest isocentric accuracy and is rotated using a computer-controlled geared motor [Figures 1 and 2]. In addition, the gantry assembly includes a built-in RFA.

Treatment delivery capability

The 6 MV photon energy is available with both flattened beam (FF) and flattening filter-free (FFF) beam options. Two flattening filters are used: one for small fields up to 16 cm × 16 cm and another for large fields up to 30 cm × 30 cm.

The available dose rates are as follows:

a. 30 MU/min to 600 MU/min for the 16 cm × 16 cm FF beam
b. 30 MU/min to 300 MU/min for the 30 cm × 30 cm FF beam
c. 30 MU/min to 800 MU/min for FFF beams.

"Siddharth II have its three variant viz. Iconic, Iconic Plus, Superia depending on the specifications." All models offer both FF and FFF beams. However, only the Siddharth Superia© model is designed for delivering Stereotactic Body Radiotherapy.

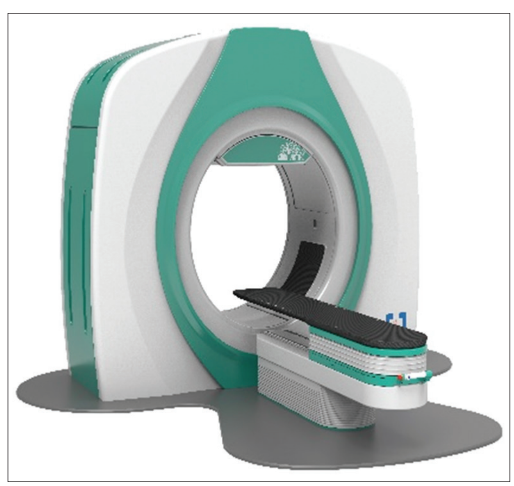

Figure 1: Siddharth II© 6 MV Linac (O Ring Model)

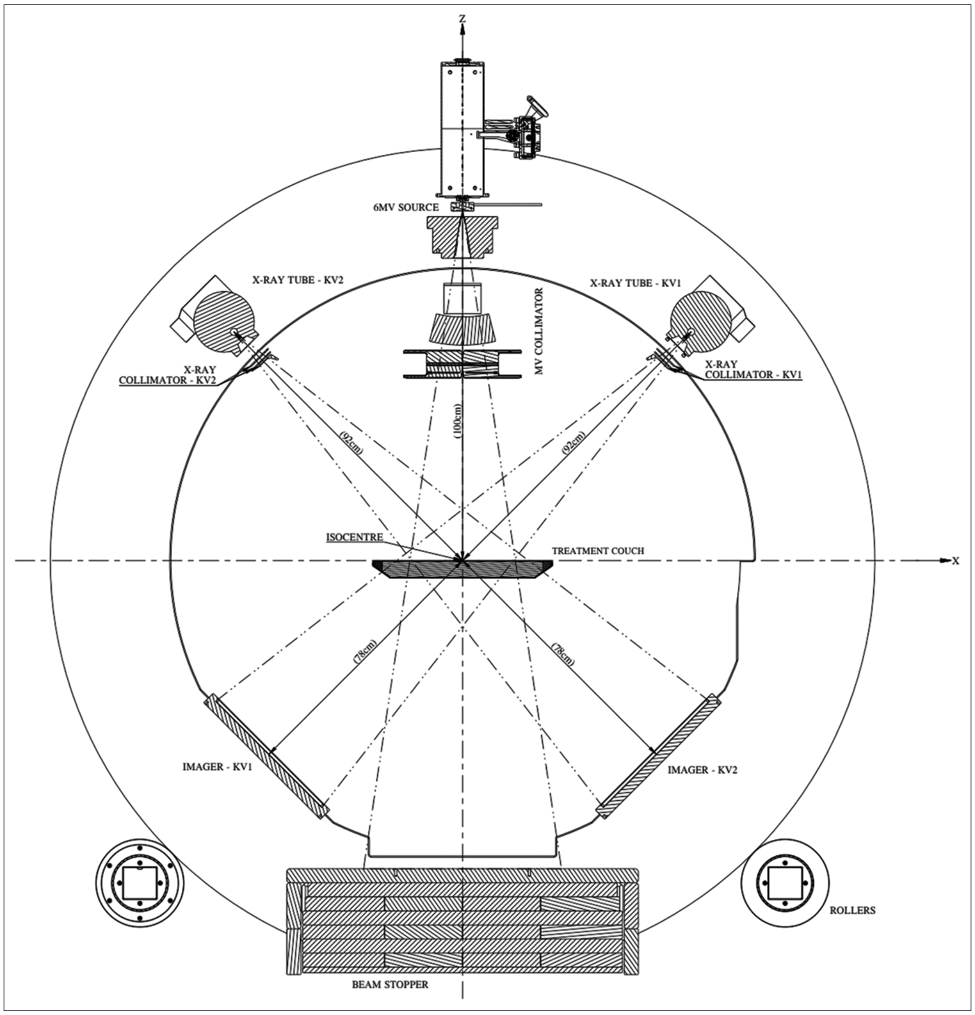

Figure 2: Siddharth II© Design of Gantry Components Ring Gantry with Beam Stopper. Bore Dia. 1.5 m

The MLC bank consists of 30 pairs of leaves (a total of 60) per side for the Iconic and Iconic Plus models, with a leaf width of 1 cm projected at the isocenter. For the Superia model, the MLC bank has 46 pairs of leaves (a total of 92). The central 16 cm (1–7 cm on either side of the center) has a leaf width of 0.5 cm at the isocenter, while the outer region, extending up to 30 cm, has a leaf width of 1 cm at the isocenter. The MLC is a tertiary collimation system, positioned after the X and Y secondary jaw sets. Design of Beam Collimation Primary, X and Y Jaw Collimators, MLC leaves is as illustrated in Figure 3. The maximum leaf speed during dynamic beam delivery is 2.5 cm/sec, with a backlash of < 0.01 cm. The MLC has a total over-travel distance of 15 cm. Leaf transmission is < 0.1%, considering a three-tenth value thickness, with an average interleaf leakage of <0.60% and a maximum of <1.3%.

For kV imaging, one or two X-ray tubes, along with a flat-panel image acquisition system, are mounted on the ring gantry, as shown in Figure 2. The Iconic Plus and Superia models feature two X-ray tubes and support dual kV imaging modes, while the Iconic model has a single X-ray tube. The kV range is 40–150 kV, and the mA range is 10–700 mA. The X-ray tube focus-to-isocenter distance is 0.92 m, and the focus-to-image receptor distance is 1.70 m. The technical specifications are brought out in a recent communication.[11] Cone-beam computed tomography imaging is supported with dual KV imaging and a tunnel-type bore aperture of 1.5 m in diameter, providing a 1.0 m clearance for the patient's surface.

Different models have some intrinsic variations in basic specifications, which are factory made, based on the institutions' requirements. The comparison of specifications of different models available is illustrated in Table 1. In Figure 3, the geometry of X and Y Collimator Jaws is shown in two perpendicular orientations. From Target, Distal End of Tertiary Collimator 48 cm, End of X Jaw 39 cm, End of Y Jaw 30 cm, End of Primary Collimator 14 cm, respectively. X and Y jaws are having focusing effect to account for divergence. MLC bank is tertiary collimator type with septa arranged linearly from center, parallel nonfocused arrangement.

Dosimetric measurements

The present work reviews the beam parameters assessed by the RFA to validate the basic specifications and performance capabilities of the manufactured Siddharth II© LE linacs

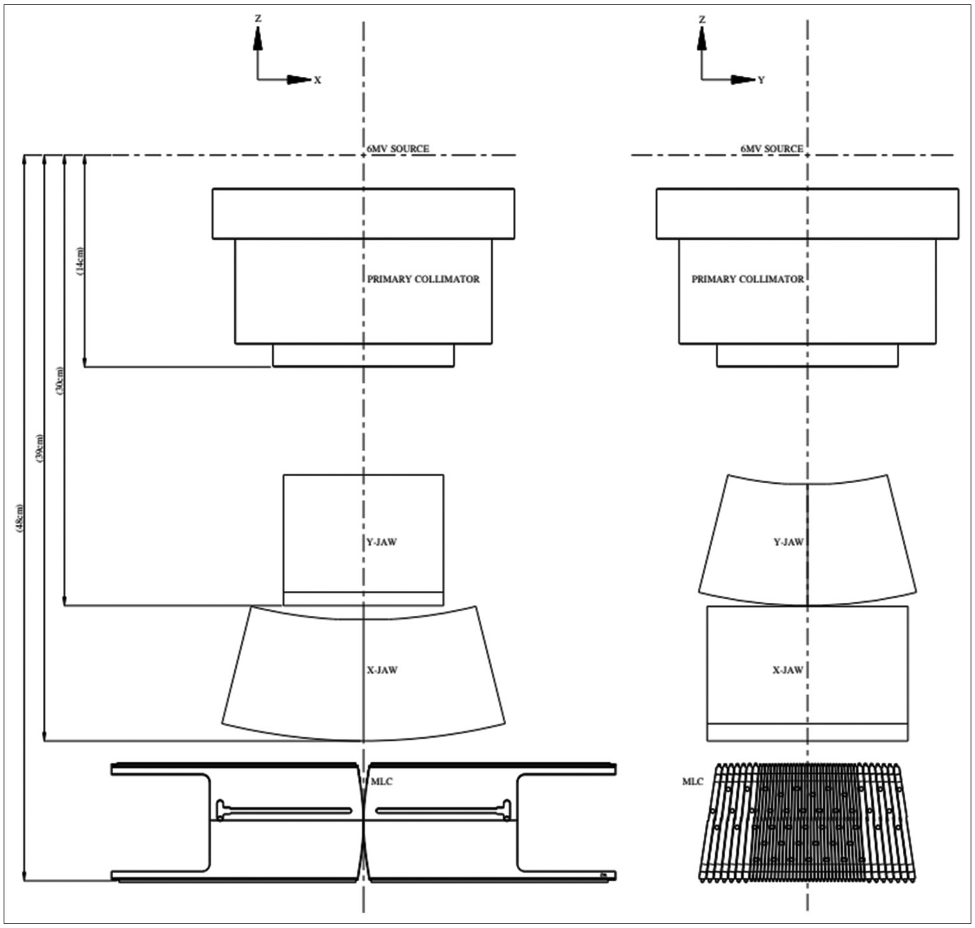

Figure 3: Siddharth II© 6MV Linac Design of Beam Collimation Primary, X and Y Collimators, MLC leaves seen in two orientations. From Target, Distal End of Tertiary Collimator 48 cm, End of X Jaw 39 cm, End of Y Jaw 30 cm, End of Primary Collimator 14 cm, respectively

installed over the past 2 years. These five machines have been type-approved and licensed for clinical use by the national regulatory authority (AERB).

A sixth 6 MV linac has been installed, tested, and its acceptance report and performance data cleared by AERB, but it is not included in this report.

A RFA, the SCANOMATIKA water tank with dimensions of 77 × 82 × 44.3 cm^3, equipped with RFA software and built into the linac head, was used for beam measurements, including both absolute and relative dosimetry. The mobile carriage allows for total X and Y axis travel from −25 cm to +25 cm, and vertical movement of 40 cm, with ±20 cm up and down movements. The positioning accuracy of the detector is 0.1 mm, with a variable speed range of 1–25 mm/s. The RFA mount, along with the motorized arms, is shown in Figure 4, illustrate the water phantom with the moving carriage designed to carry the ion chamber or semiconductor diode.

A dedicated precision electrometer is used to measure integrated dose and dose rate, which are applicable for radiation profiles and absolute measurements. Radiation beam profiles (both in-line and cross-line) and central axis depth dose measurements were carried out for all field sizes and used for beam configuration in the treatment planning system. An IBA 0.04 cc (CC04) mini ion chamber was used in the RFA. Analysis of all acquired profile scans was performed using the in-built RFA software.

The radiation isocenter verification was performed using the spoke test with EBT 3-Gafchromic film. Four nonoverlapping beams at different gantry and collimator angles were used, with slit beams of 0.1 cm × 20 cm, employing MLC. The film was scanned using an Epson scanner (EPSON 12000 XL) following standard protocol.

Output measurements were based on the IAEA TRS 398[12] protocol for a 10 cm × 10 cm field at an SSD of 100 cm, using a 0.6 cc ionization chamber (Sun Nuclear) at reference depths of d_{max} 1.5 cm and 10 cm. The obtained radiation beam characteristics and specifications were compared with those of the TrueBeam© SVC with FFF model (M/s Varian AG, USA) 6 MV photon beam,[13] using cylindrical water phantom RFA (Sun Nuclear, USA) measurements. The TrueBeam model was previously licensed at our institution in 2023.

Table 1: Basic specifications in different Siddharth II models

Design aspects	Siddharth II 6 MV LE linac models			
	Iconic	**Iconic plus**	**Superia**	**Superia plus**
Treatment modes	3D CRT, IMRT, VMAT	3D CRT, IMRT, VMAT	3D CRT, IMRT, VMAT, SBRT	3D CRT, IMRT, VMAT, SBRT, SRS
Patient support assembly	3 dimension capability	6 dimension (with pitch and roll)	6 dimension (with pitch and roll)	6 dimension (with pitch and roll)
KV imaging	Single kV (single, CBCT)	Dual kV AP and Lat; any angle Stereo sim. Images, upto 150°	Dual kV AP and Lat; any angle Stereo Sim. Images, upto 150°	Dual kV AP and Lat; any angle Stereo Sim. Images, upto 150°
MLC configuration	FieldSize: 30 cm × 30 cm. 30 leaf pairs: With 1 cm leaf width	Field size: 30 cm × 30 cm. 30 leaf pairs: With 1 cm leaf width	Field size: 30 × 30 cm Leafs pairs: 46 Middle 16 cm leaf pairs with 0.5 cm leaf width (32 pairs). Remaining 14 cm till 30 cm, leaf widths 1 cm (14 pairs)	Field size: 30 × 30 cm Leafs pairs: 46 Middle 16 cm leaf pairs with 0.5 cm leaf width (32 pairs). Remaining 14 cm till 30 cm. Leaf widths 1 cm (14 pairs) SRSMLC: Automatic retractable. Leaf pairs: 50 with 0.2 cm leaf width

MLC: Multi-leaf collimator, KV: Kilo-voltage, CRT: Conformal radiotherapy, IMRT: Intensity modulated radiation therapy, VMAT: Volumetric-modulated arc therapy, SBRT: Stereotactic body radiotherapy, CBCT: Cone-beam computed tomography, 3D: Three dimensional, LE: Low energy, AP: Antero-posterior, SRS: Stereotactic radiosurgery, SRSMLC: SRS multi-leaf collimator

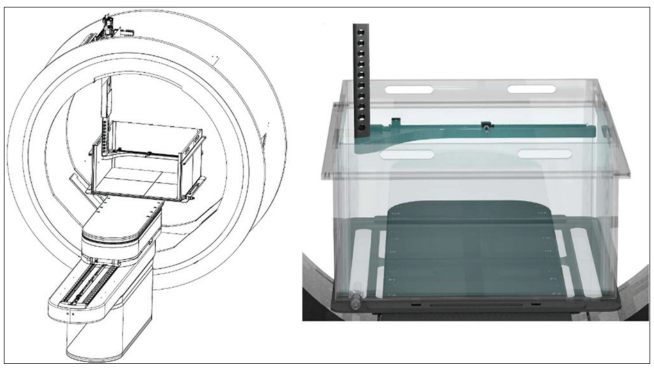

Figure 4: (Left) SCANOMATIKA radiation field analyser of unique design built in as a Retractable Accessory Arm, on the Gantry O Ring Assembly independently. (Right) water phantom shown could be positioned as insert to accessory chamber carriage. Computer controlled Movements along with digital display appear on a panel in the control console

Results

The results of the beam data analysis are presented in Tables 2-7, highlighting the accuracy and consistency of the measured radiation parameters against the prescribed specifications. These data are compared with regulatory acceptance limits[14] and show that the measured parameters are within the required thresholds for clinical applications. Table 2 shows the measured and extracted radiation beam data, which are compared with the machine's specifications for acceptance purposes and submitted to the Regulatory Authority. Figure 5 highlights the RFA measured PDD curves, overlaid radiation beam profiles of Small Flatness Filter IN and CR planes. They show clinically acceptable beam delivery. Table 3 shows the radiation beam delivery capabilities and Table 4 shows the radiation safety features in the machine beam generator. Table 5 highlights IMRT related radiation parameters, and Table 6 relates to VMAT parameters compliance.

The measured parameters of the 6 MV beam from the compared TrueBeam© linac [last column in Tables 2-7], which also received clearance from the same regulatory authority, AERB, based on our institutional report,[13] show almost the same dosimetric parameters as the Siddharth II© model. Output factors [Table 7] at a 100 cm focus-to-chamber distance with a depth of 10 cm show good agreement within 1%–2%. The MLC, with a leaf width of 1 cm at the isocenter, conforms to earlier international standards.[15] The leaf edges are rounded type, but septas are vertical and for film dosimetry spoke test purposes, a minimum radiation field width of 1 mm is achievable. The dosimetric parameters measured from the five Siddharth II© linacs highlight that they are acceptable for clinical use.

Discussion

The presentation has brought out the various dosimetric and radiation safety parameters measured during the five new installations of new model LE linear accelerator manufactured in India. One more Iconic Plus model Siddharth II© had similar parameters showed in QA tests, is also Licensed, but not included in this report. The specifications desired for the 6 MV photon both for flattened and unflattened beams are maintained, and much below the tolerance values provided by AERB document.[14] It is also ascertained that the beam is comparable with well tested imported linac from M/s Varian, AG.

The new indigenous design, the Siddharth II© Iconic models have 30 pairs of 1 cm MLC width at isocenter (for field size of 30 cm × 30 cm). Siddharth II Superia models have 5 mm MLC resolution in the center. Middle 16 cm leaf pairs with 0.5 cm leaf width (32 pairs). Remaining 14 cm till 30 cm, leaf widths 1 cm (14 pairs) totalling to 46 leaf pairs, covering 30 cm × 30 cm

Table 2: Comparison of 6 MV radiation beam parameters

Specifications	Tolerance	Beam data for Siddharth II© Linac at different installations					Beam data – true beam HE Linac (6 MV)
		A - Iconic	B - Iconic plus	C - Iconic plus	D - Superia	E - Iconic plus	
Radiation Iso centre (by spoke test)	2 mm dia.	0.26 mm dia.	0.43 mm dia.	0.65 mm dia.	0.32 mm dia.	0.72 mm dia.	1.0 mm dia.
Overlap (10×10) (Jaws) Parallel. Opposed. Fields	Within 3 mm	1.92 mm (IN) 0.13 mm (CR)	1.10 mm (IN) 1.58 mm (CR)	1.26 mm (IN) 1.21 mm (CR)	0.60 mm (IN) 0.06 mm (CR)	0.40 mm (IN) 0.90 mm (CR)	0.45 mm (IN) 0.71 mm (CR)
Overlap (10×10) (MLC) Parallel. Opposed. Fields	Within 3 mm	1.22 mm (IN) 1.25 mm (CR)	0.13 mm (IN) 0.05 mm (CR)	0.92 mm (IN) 1.27 mm (CR)	0.18 mm (IN) 0.34 mm (CR)	0.20 mm (IN) 0.20 mm (CR)	0.35 mm (IN) 0.33 mm (CR)
Flatness (d=10)							
6×6 field	106%	102.7% (IN) 102.5% (CR)	102.5% (IN) 102.1% (CR)	103.4% (IN) 102.1% (CR)	102.5% (IN) 102.3% (CR)	102.7% (IN) 102.8% (CR)	101.6% (IN) 101.9% (CR)
10×10 field		103.6% (IN) 103.8% (CR)	104.1% (IN) 103.6% (CR)	103.5% (IN) 102.5% (CR)	103.8% (IN) 103.6% (CR)	104.4% (IN) 103.9% (CR)	105.2% (IN) 104.9% (CR)
30×30 field		103.5% (IN) 103.5% (CR)	104.0% (IN) 103.7% (CR)	105.9% (IN) 104.6% (CR)	104.9% (IN) 103.7% (CR)	103.4% (IN) 103.0% (CR)	104.5% (IN) 104.2% (CR)
Symmetry							
6×6 field	103%	102.4% (IN) 100.7% (CR)	100.8% (IN) 100.3% (CR)	101.8% (IN) 100.4% (CR)	100.5% (IN) 100.4% (CR)	100.5% (IN) 100.4% (CR)	100.6% (IN) 100.9 (CR)
10×10 field		100.6% (IN) 100.3% (CR)	101.0% (IN) 100.6% (CR)	101.8% (IN) 100.5% (CR)	100.8% (IN) 100.6% (CR)	100.8% (IN) 101.0% (CR)	100.6% (IN) 100.2 (CR)
30×30 field		100.9% (IN) 100.8% (CR)	100.6% (IN) 100.7% (CR)	100.8% (IN) 100.5% (CR)	100.5% (IN) 100.7% (CR)	100.9% (IN) 101.0% (CR)	100.6% (IN) 100.3 (CR)
Rad penumbra (mm) (dmax)	10	4.4 L, 4.5 R (IN) 5.0 L, 4.7 R (CR)	4.4 L, 4.1 R (IN) 4.8 L, 4.9 R (CR)	4.9 L, 5.4 R (IN) 5.0 L, 5.2 R (CR)	4.9 L, 5.4 R (IN) 5.3 L, 5.5 R (CR)	5.9 L, 5.4 R (IN) 5.4 L, 6.0 R (CR)	5.3 L, 5.5 R (IN) 5.0 L, 5.2 R (CR)
Quality index $TPR_{20,10}$	0.667	0.663 (FF)	0.662 (FF) 0.632 (FFF)	0.660 (FF) 0.624 (FFF)	0.672 (FF) 0.640 (FFF)	0.673 (FF) 0.641 (FF)	0.669 (FF) 0.60 (FFF)
Surface dose 5 mm, 30×30	<60%	57.8% (FF)	40.1% (FF) 40.3% (FFF)	40.4% (FF) 40.3% (FFF)	58.8% (FF) 59.4% (FFF)	37.7% (FF) 41.9% (FFF)	58.3% (FF) 63.5% (FFF)
Depth $dose_{max}$ 10×10 field (mm)	15±2	15.5	15.2	13.2	13.6	16.0	15.9
%D.D 10 cm	67.5±2	66.7	66.2	65.9	67.1	67.8	66.9

FF: Flattened beam, FFF: FF-free, MLC: Multi-leaf collimator, TPR: Tissue phantom ratio, HE: High energy

Table 3: Comparison of clinical beam delivery 6 MV radiotherapy beams

Specifications	Tolerance	Beam data for Siddharth II© Linac at different installations					Beam data – true beam HE Linac (6 MV)
		A - Iconic	B - Iconic plus	C - Iconic plus	D - Superia	E - Iconic plus	
Energy stability (full day)	COV±1.0%	0.19%	0.05%	0.05%	0.32%	0.14%	0.39%
Reproducibility of output 10×10	COV±0.5%	±0.025%	±0.08%	±0.07%	±0.08%	0.06%	±0.045%
Output consistancy (full day)	2.0%	0.23%	0.15%	0.11%	0.10%	0.18%	0.37%
Output consistancy with gantry angle (0°, 90°, 180°, 270°)	2.0%	0.03%, 0.03%, 0.10%, 0.06%	0.03%, 0.00%, 0.00%, 0.00%	0.04%, 0.06%, 0.25%, 0.09%	0.04%, 0.03%, 0.01%, 0.03%	0.06%, 0.18%, 0.16%, 0.06%	0.00%, 0.49%, 0.67%, 0.13%
Monitor response with gantry rotation for 10×10 field	3.0%	0.11%, 0.42%, 0.11%, 0.78%	0.03%, 0.02%, 0.03%, 0.03%	0.04%, 0.06%, 0.25%, 0.09%	0.04%, 0.03%, 0.01%, 0.03%	0.06%, 0.18%, 0.16%, 0.06%	0.00%, 0.35%, 0.74%, 0.08%
Linearity of monitor chamber (External Electrometer)	COV 2%	1.72%	0.28%	0.22%	0.82%	0.16%	0.11%
Temporal stability of output (day)	COV 2%	0.0018%	0.12%	0.18%	0.13%	0.18%	0.16%

HE: High energy, COV: Coefficient of variations

irregular fields.[11] Superia Plus model has 2 mm resolution for Stereotactic treatments compared to high resolution micro MLC models available from other manufacturers [Table 1]. True Beam Varian, described in this comparison has Millenium MLC, with 40 pairs of 5 mm MLC in the center and 20 pairs of 1 cm MLC and peripheral 20 pairs of width 1 cm.

Table 4: Comparison of Linac beam generator radiation safety

Specifications	Tolerance	Beam data for Siddharth II© Linac at different installations					Beam data true beam HE Linac (6 MV)
		A - Iconic	B - Iconic plus	C - Iconic plus	D - Superia	E - Iconic plus	
Maximum Photon leakage beam limiting jaws (%)	2	X - 0.16 Y - 0.14	X - 0.17 Y - 0.17	X - 0.18 Y - 0.14	X - 0.13 Y - 0.14	X - 0.17 Y - 0.12	X - 0.47 Y - 0.47
Mean photon leakage (Jaws) (%)	0.75	X - 0.13 Y - 0.13	X - 0.15 Y - 0.15	X - 0.12 Y - 0.11	X - 0.13 Y - 0.14	X - 0.15 Y - 0.12	X - 0.37 Y - 0.38
MLC (tertiary) (%)	5	Maximum 0.62 Average 0.38	Maximum 0.65 Average 0.45	Maximum 0.88 Average 0.46	Maximum 1.26 Average 0.62	Maximum 0.50 Average 0.32	Maximum 1.01 Average 0.80
Maximum photon leakage patient plane (%)	0.2	0.130	0.015	0.012	0.116	0.015	0.02
Mean photon leakage patient plane (%)	0.1	0.03	0.007	0.006	0.056	0.006	0.008
Mean photon leakage 1 m from target (%)	0.5	0.09	0.01	0.02	0.23	0.050	0.032
Mean photon leakage 5 cm from machine surface (%)	No Spec.	0.001	0.012	0.005	0.016	0.006	0.03

MLC: Maximum photon leakage, HE: High energy

Table 5: Comparison of intensity-modulated beam delivery capability

Specifications	Tolerance	Beam data for Siddharth II© Linac at different installations					Beam data true beam HE Linac (6 MV)
		A - Iconic	B - Iconic plus	C - Iconic plus	D - Superia	E - Iconic plus	
Couch positional reproducibility isocentre (mm)	±2 mm	Longi - 0.01 Later - 0.04 Verti - 0.03	Longi - 0.05 Later - 0.05 Verti - 0.05	Longi - 0.05 Later - 0.05 Verti - 0.05	Longi - 0.01 Later - 0.04 Verti - 0.03	Longi - 0.05 Later - 0.05 Verti - 0.05	Longi - 0.2 Later - 0.1 Verti - 0.2
Laser alignment with isocentre	1.5 mm	1.0 mm	1.0 mm	1.0 mm	1.0 mm	1.0 mm	1.0 mm
Leaf position accuracy/reproducibility (mm)	±1 mm	0.4 mm	90° - 0.34 180° - 0.48 270° - 0.48	90° - 0.38 180° - 0.50 270° - 0.48	90° - 0.41 180° - 0.36 270° - 0.48	90° - 0.45 180° - 0.40 270° - 0.44	90o - 0.5 180o - 0.5 270o - 0.5
Tolerance of leaf speed (COV on 0.5 cm/s)	COV - 0.5	0.060	0.007	0.011	0.003	0.052	0.01
Output consistancy low MU	COV - ≤5%	4 MU 1.02%	4 MU 0.06%	4 MU 0.34%	4 MU 1.15%	4 MU 0.11%	0.28%
Output consistancy at highest/lowest D/rate	≤2%	Low - 0.12% High - 0.02%	Low - 0.08% High - 0.00%	Low - 0.02% High - 0.08%	Low - 0.02% High - 0.08%	Low - 0.01% High - 0.03%	1.22%
Output consistancy at 0° ,90°, 180°, 270°	±1%	0.03%, 0.03%, 0.10%, 0.06%	0.03%, 0.00%, 0.00%, 0.00%	0.04%, 0.06%, 0.25%, 0.09%	0.07%, 0.04%, 0.03%, 0.05%	0.07%, 0.04%, 0.03%, 0.05%	Max 0.02%
Beam flatness consistancy 5×5 field, d=10 cm	±1%	IN - 0.09% CR - 0.09%	IN - 0.06% CR - 0.08%	IN - 0.05% CR - 0.09%	IN - 0.13% CR - 0.06%	IN - 0.19% CR - 0.04%	Max. Devn. 0.14% (IN)
Beam symmetry consistancy 5×5 field, d=10 cm	±1%	IN - 0.04% CR - 0.03%	IN - 0.08% CR - 0.03%	IN - 0.06% CR - 0.02%	IN 0.10% CR - 0.14%	IN - 0.19% CR - 0.04%	Max. Devn. 0.12% (IN)
Consistancy of %DD, 10×10, 10 cm	COV 1%	FF - 0.08%	FF - 0.04% FFF - 0.04%	FF - 0.06% FFF - 0.01%	FF - 0.21% FFF - 0.15%	FF - 0.03% FFF - 0.15%	Max. Devn. 0.06%
Consistancy of TMR/TPR, 10 cm	COV 1%	FF - 0.08%	FF - 0.03% FFF - 0.01%	FF - 0.06% FFF - 0.05%	FF - 0.11% FFF - 0.15%	FF - 0.16% FFF - 0.08%	Max. Devn. 0.21%
Leaf positioning accuracy (garden Fence) (maximum)	0.5 mm	0° - 0.44 90° - 0.39 Arc - 0.35	0° - 0.34 90° - 0.48 Arc - 0.48	0° - 0.35 90° - 0.40 Arc - 0.33	0° - 0.41 90° - 0.36 Arc - 0.48	0° - 0.45 90° - 0.40 Arc - 0.44	Max. Devn. 0.24 mm

FF: Flattened beam, FFF: Flattening filter-free, HE: High energy, COV: Coefficient of variations, TMR/TPR: Tissue max. ratio tissue phantom ratio

This report has highlighted that as a LE linac model manufactured from India, with O ring design can be safely used for external-beam radiotherapy. All the functioning of the machine is computer controlled, with facilities of easy patient positioning. Before installation in the customer site, the linac and collimator assembly is well tested for beam alignment, symmetry and reproducibility, thoroughly by group of test engineers, and all parameters have showed little variations during acceptance time and quality evaluation. Review of measured parameters highlighted

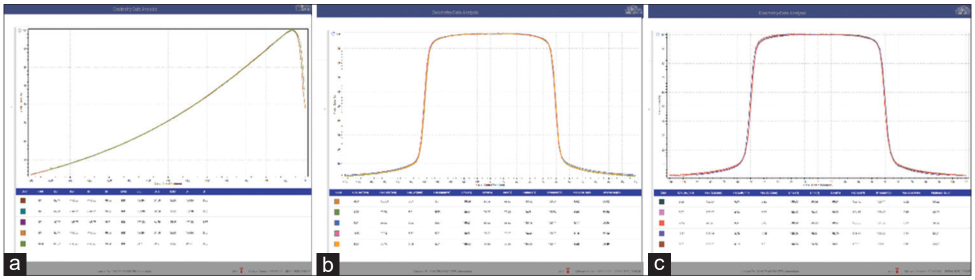

Figure 5: (a) Siddharth II 5 machines' overlaid percentage DD curves, showing reproducible Beams (b) 10 cm × 10 cm Field Size "In Plane" Flatness Profiles for 5 different installations (SF) (c) 10 cm × 10 cm Field Size "Cross Plane Flatness Profiles for 5 different installations (SF)

Table 6: Comparison of linac for volumetric-modulated arc therapy

Specifications	Tolerance	Beam data for Siddharth II© Linac at different installations					Beam data true beam HE Linac (6 MV)
		A - iconic	B - iconic plus	C - iconic plus	D - superia	E - iconic plus	
Accuracy gantry speed	<1o/s	0.8°/s	0.6°/s	0.5°/s	0.5°/s	0.1°/s	0.5°/s
Maximum leaf speed	As per Spec.	22 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s	25 mm/s
Maximum gantry speed	As per Spec.	5.8°/s	6.9°/s	6.9°/s	6.9°/s	6.9°/s	
Accuracy leaf speed	≤2%	1.16%	1.20%	1.9%	1.2%	1.2%	0.27%
Accuracy leaf position (maximum)	<0.5 mm	0° - 0.44 90° - 0.39 Arc - 0.3	0° - 0.34 90° - 0.48 Arc - 0.48	0° - 0.35 90° - 0.40 Arc - 0.33	0° - 0.41 90° - 0.36 Arc - 0.48	0° - 0.45 90° - 0.40 Arc - 0.44	0° - 0.25 90° - 0.24
Arc. mode monitor constancy	≤2%	0.033%	0.26%	0.61%	0.73%	0.78%	0.60%
Output constancy with D/R arc	≤2%	0.02%	0.02%	0.13%	0.87%	0.85%	0.40%
Accuracy dose with D/R and gantry speed	≤2%	0.05%	0.71%	0.57%	0.21%	0.88%	90° - 0% 180° - 1.5% 270° - 0.75%
Beam flatness full arc	≤2%	IN - 0.11% CR - 0.10%	IN - 0.01% CR - 0.30%	IN - 0.11% CR - 0.99%	IN - 1.90% CR - 0.10%	IN - 0.09% CR - 0.12%	0.36%
Beam flatness constancy, arc	1%	IN - 0.02% CR - 0.03%	IN - 0.01% CR - 0.06%	IN - 0.27% CR - 0.93%	IN - 0.05% CR - 0.06%	IN - 0.03% CR - 0.13%	0.10%
Beam symmetry full arc	≤2%	IN - 0.24% CR - 0.93%	IN - 0.16% CR - 0.93%	IN - 0.44% CR - 0.93%	IN - 1.99% CR - 0.15%	IN - 0.40% CR - 0.34%	0.02%
Beam symmetry	1%	IN - 0.02% CR - 0.14%	IN - 0.08% CR - 0.15%	IN - 0.44% CR - 0.92%	IN - 0.03% CR - 0.06%	IN - 0.03% CR - 0.23%	0.25%
Constancy arc beam quality const	±1%	FF - 0.10%	FF - 0.06% FFF - 0.02%	FF - 0.01% FFF - 0.16%	FF - 0.05% FFF - 0.08%	FF - 0.07% FFF - 0.06%	0.03%

FF: Flattened beam, FFF: Flattening filter-free, D/R: Dose rate

Table 7: Output factors at focus-to-chamber distance 100 cm, depth=10 cm

Beam quality	Field size (cm × cm)	Siddh-II - Iconic	Siddh-II - Iconic plus	True beam SVC	Beam quality	Field size (cm × cm)	Siddh-II - Iconic	Siddh-II – Iconic plus	True beam SVC
6 × (FF)	2×2	0.800	0.796	0.790	6× (FFF)	2×2	0.809	0.805	0.799
	4×4	0.878	0.869	0.864		4×4	0.884	0.878	0.876
	6×6	0.929	0.922	0.922		6×6	0.935	0.930	0.930
	10×10	1.000	1.000	1.000		10×10	1.000	1.000	1.000
	16×16	1.076	1.076	1.066		16×16	1.062	1.061	1.054
	20×20	1.107	1.114	1.096		20×20	1.086	1.087	1.076
	30×30	1.155	1.171	1.139		30×30	1.116	1.123	1.106
	6×20	0.983	0.977	0.974		6×20	0.988	0.980	0.977
	20×6	0.994	0.990	0.989		20×6	0.989	0.985	0.984

FF: Flattened beam, FFF: Flattening filter-free, SVC: Small vault configuration in this report highlighted that manufactured linacs from M/s PMT Works has clearly shown that they perfected manufacturing process to deliver clinically acceptable EBRT linacs.

Conclusion

This report highlights the successful implementation of the Siddharth II© LE linac in clinical settings, with its performance meeting or confirming the regulatory requirements. The dosimetric parameters, radiation safety features, and beam delivery capabilities demonstrate that the Siddharth II© linac is a reliable and cost-effective alternative to imported models. With its innovative design and high accuracy, the Siddharth II© linac provides an essential tool for cancer treatment, ensuring that the needs of India's growing population are met. Furthermore, the Siddharth II© linac is part of India's larger "Make in India" initiative, which promotes self-reliance in the field of medical technology. This indigenous model, with its advanced technology and regulatory approvals, represents a significant step forward in making high-quality, affordable cancer treatment more accessible to patients across the country.

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Conflicts of interest

There are no conflicts of interest.

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