An Analysis of Radiotherapy Machine Requirements in India: Impact of the Pandemic and Regional Disparities

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Abstract

Aim: This article examines India's present radiotherapy (RT) machine status and requirements, geographical distribution, and infrastructure need in six regional areas, which include 31 member states and union territories (UTs). It also considers the influence of the COVID-19 pandemic on India's teletherapy sector. **Materials and Methods:** Data from reliable resources, including Atomic Energy Regulatory Board, Global Cancer Observatory, and Directory of Radiotherapy Centres databases, were used to analyze the current status of RT machine (RTM) density, regional disparity, and COVID-19 impact on infrastructure growth-rate. **Results:** In India, the number of functioning RTM and facilities are 823 and 554, respectively, with an average of 1.5 RTM per institute, of which 69.4% have only one RTM. Over the past 22 years, there has been a paradigm shift towards medical linear accelerator (linac) installation instead of telecobalt machines. Presently, there is a teletherapy density of 0.6 RTM per million population, and there is a shortfall of 1209 RTMs. There is a considerable regional disparity in the distribution of RTMs, ranging from (0.08 RTM/million–2.94 RTM/million) across different regions. There is a significant demand for RTMs in the Northern region (480) and the state of Uttar Pradesh (279). The COVID-19 pandemic temporarily impacted India's RT growth rate, reducing it from 5% to 1.9% in 2020–2021. **Conclusions:** New policies must be established to accelerate the rate of RT installation growth. To better serve local populations and save patient costs, this article proposes that RT facilities be dispersed equitably across states.

Keywords: COVID-19, health policy, oncology, particle accelerators, radiotherapy

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Introduction

The growing global burden of cancer has become a major concern, with projections indicating a 47% increase in cancer cases by 2040.[1] Almost half of all cancer cases require radiotherapy (RT) once in their lifetime, thus increasing demand for RT machines (RTM) with advanced technology in recent years.[2] RTMs use high-energy radiation to treat cancer by destroying cells and shrinking tumor. It can be used alone or with other treatments to treat many types of cancer, such as head and neck, lung, breast, and prostate.[3] The role of RT in a palliative setting is already established.[4] Recent advances in technology, such as linear accelerators (linacs) and proton therapy machines, have enhanced the targeting, accuracy, and effectiveness of the treatment.[5]

However, in many parts of the world, there is a shortage of these machines due to various socio-economic factors.[6-8] This shortage results in long wait times for patients who need RT and also leads to suboptimal care.[9] The geographic distribution of these machines also has an impact on a country's cancer control effort by limiting patients' access to vital treatment options. This phenomenon can result in unequal access to care and disparities in health outcomes among different populations within the country.[10]

With its large population and diverse cultural and ethnic landscape, India has a significant cancer burden, accounting for 6.8% of all cancer cases globally.[11] This is especially worrisome in light of the predicted increase in noncommunicable diseases (NCDs), with 63% of deaths in India attributed to NCDs by 2020.[12] This condition was more worsened

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due to the recent COVID-19 pandemic, which impacted healthcare systems worldwide by disrupting the supply chain, thus resulting in difficulty in acquiring new RTMs and equipment.[13,14] Despite the acknowledged impact of the pandemic on cancer care, research on the current RT infrastructure in India has been limited, with no regional distribution analysis of RTM numbers and utilization.

We aim to provide a thorough analysis of RTMs in India, including historical trends, regional distribution, and the effect of the COVID-19 pandemic. Our study intends to categorize RTMs and assess the replacement of older RTMs with more advanced technology. In addition, we intend to evaluate the demand for additional RTMs in India's various regions and states. We hypothesized that there is a deficiency of RTMs in India, resulting in unequal access to care and disparities in health outcomes between populations within the country. In addition, the COVID-19 pandemic has had a negative impact on the availability and use of RTMs in India.

By conducting this study, we hope to gain a better understanding of the current status of RTMs in India and to inform efforts to improve access to cancer care for India's growing cancer patient population.

Materials and Methods

Data collection

The data for this study were sourced from several reputable sources. The annual trend data for radiotherapy institutes (RTIs) and RTMs from the Atomic Energy Regulatory Board annual status reports archive.[15] Cancer incidence data collected from the Global Cancer Observatory (GCO) database and Indian Council of Medical Research (ICMR) report 2016.[11,16] RTMs per institute data from the International Atomic Energy Agency's (IAEA) Directory of Radiotherapy Centres (DIRAC) data repository.[17] Data obtained from the DIRAC repository were verified and corrected with the help of a network of RT professionals. Population data were taken from Worldometer website and Unique Identification Authority of India estimations for 2021.[18,19]

Methodology

The RTMs and RTIs were divided into Indian states or union territories (UTs) and regional zones. Indian states or UTs without RTIs were not included in the study as their treatment was provided by other Indian states and UTs. Following the exclusion criteria, the data was collected for 31 Indian states and UTs, excluding the Andaman and Nicobar Islands, Daman and Diu, and Lakshadweep UTs. To understand the zone-wise deficiency, the Indian states and UTs were divided into six regional zones: north, North-East, West, East, Center, And South. Table 1 depicts the Indian states and UTs that fall under each zone. To account for the recent technological advancements, the RTMs were grouped into linacs, Tomotherapy, Cyberknife (CK), Gamma Knife (GK), and telecobalt (TC) machines.

Estimating radiotherapy patients, radiotherapy machines, and radiotherapy machine density for Indian States and Union Territories

The projected RT patients (RTP) for each Indian state and UT for the year 2022 can be calculated using equation (1):

$$RTP = \mathrm{NCI(2016)/million * 1.20 * RUR * RTF * EP} \qquad (1)$$

Here, NCI (2016)/million represents the new cancer cases per million population in the year 2016, sourced from the ICMR survey report specific to each Indian state and UT.[16] The incorporation of a factor of 1.20 accounts for an anticipated 20% rise in new cancer incidences from 2016 to 2022[16,20] The parameter RUR denotes the RT utilization rate, standardized at 0.55, indicating that 55% of all cancer patients are expected to undergo RT treatment at least once during their lifetime.[21] RTF, signifying the re-treatment factor, is assigned a value of 1.25, denoting a 25% increase in the proportion of RTP necessitating re-treatment.[22] Estimated population (EP) represents the EP in Indian states and UTs in the year 2022 in millions.

Using equation (1), projected/estimated radiotherapy machines (ETM) can be calculated as shown in equation (2):

$$ETM = \frac{RTP}{450} \qquad (2)$$

The selection of factor 450 is taken from recommendations outlined in the IAEA report, advocating for the provision of 1 teletherapy machine per 450 RTP.[22]

Using equation (2), projected RT machine density (ETM/million) can be calculated as:

Table 1: Six regional zones and corresponding 31 Indian states and union territories (numbers in parenthesis)

Regional zones	North (8)	East (4)	South (6)	West (3)	Centre (2)	North-East (8)
States	Jammu and Kashmir	Bihar	Andhra Pradesh	Goa	Chhattisgarh	Arunachal Pradesh
	Himachal Pradesh	Jharkhand	Karnataka	Gujarat	Madhya Pradesh	Assam
	Punjab	Odisha	Kerala	Maharashtra		Nagaland
	Haryana	West Bengal	Tamil Nadu			Sikkim
	Delhi		Telangana			Manipur
	Rajasthan		Puducherry			Meghalaya
	Uttar Pradesh					Mizoram
	Uttarakhand					Tripura

$$ETM\ /\ million = \frac{ETM}{EP} \quad (3)$$

The current teletherapy density (CTM/million) for each Indian state and UT for the year 2022 can be calculated using equation (4) below:

$$CTM\ /\ million = \frac{CTM}{EP} \quad (4)$$

Here, CTM represents the total number of teletherapy machines in the Indian states and UTs at the time of writing of the paper, and EP represents the EP in Indian states and UTs in the year 2022 in millions.

Estimating impact of COVID-19

To evaluate the influence of the COVID-19 pandemic on RT installations, prepandemic installations were extrapolated for 2020, 2021, and 2022 using the linear extrapolation method, assuming the future values will change at a constant rate based on past values, and compared with existing installations. Contributions from other factors such as market conditions, competition, and technological advancements were neglected in making predictions.

Results

Radiotherapy institutes and radiotherapy machine statistics of India in the year 2022

Figure 1 illustrates the RTM statistics in India in 2022. In India, the average number of RTMs per institute stands at 1.5. Notably, 69.4% of RTIs have only one RTM per institute and 20.4% have two RTMs per institute. 6.4% of institutions have installed three RTMs, while 3.6% of institutions have installed more than three RTMs, as shown in Figure 1a. There are 554 RTIs and 823 RTMs in total, with 624 (75.8%) of them being linacs, 151 (18.3%) being TC machines, and 48 (5.9%) being other (GK, CK, and Tomotherapy), as shown in Figure 1b.

Changing radiotherapy installation trend from 2000 to 2022

Figure 2 depicts the evolution of RT installation over the last twenty-two years. In 2011-2012, linacs outnumbered TC machines in India. The replacement of traditional TC machines with new RTMs, such as linacs and other advanced RTMs, is depicted in Figure 3. In 2000, linacs accounted for 12.2% of all RTMs; by 2010, this percentage had increased to 43.1%, and by 2022, it had reached 75.8%. In the past 22 years, the percentage of TC machines has steadily but gradually decreased. The market share of Tomotherapy machines (or derivatives) increased from 0.7% in 2010 to 3.8% in 2022. The number of RTMs such as CK and GK has remained unchanged over the past decade.

Geographical distribution of radiotherapy institutes and radiotherapy machines in six zones and 31 Indian states in the year 2022

Figure 4a and b depicts the current distribution of RTIs and RTMs across the various geographical zones and states of India. The southern region of India has the most RTMs and RTIs (34.5% and 35%, respectively), while the North-Eastern region has the fewest RTMs and RTIs (4.5%, 4.5%). The state with the highest proportion of RTIs and RTMs is Maharashtra (14.3% and 13.4%, respectively), followed by Tamil Nadu (10.6% and 9.7%) and Uttar Pradesh (7.8%, 7.2%). The states of Tripura, Mizoram,

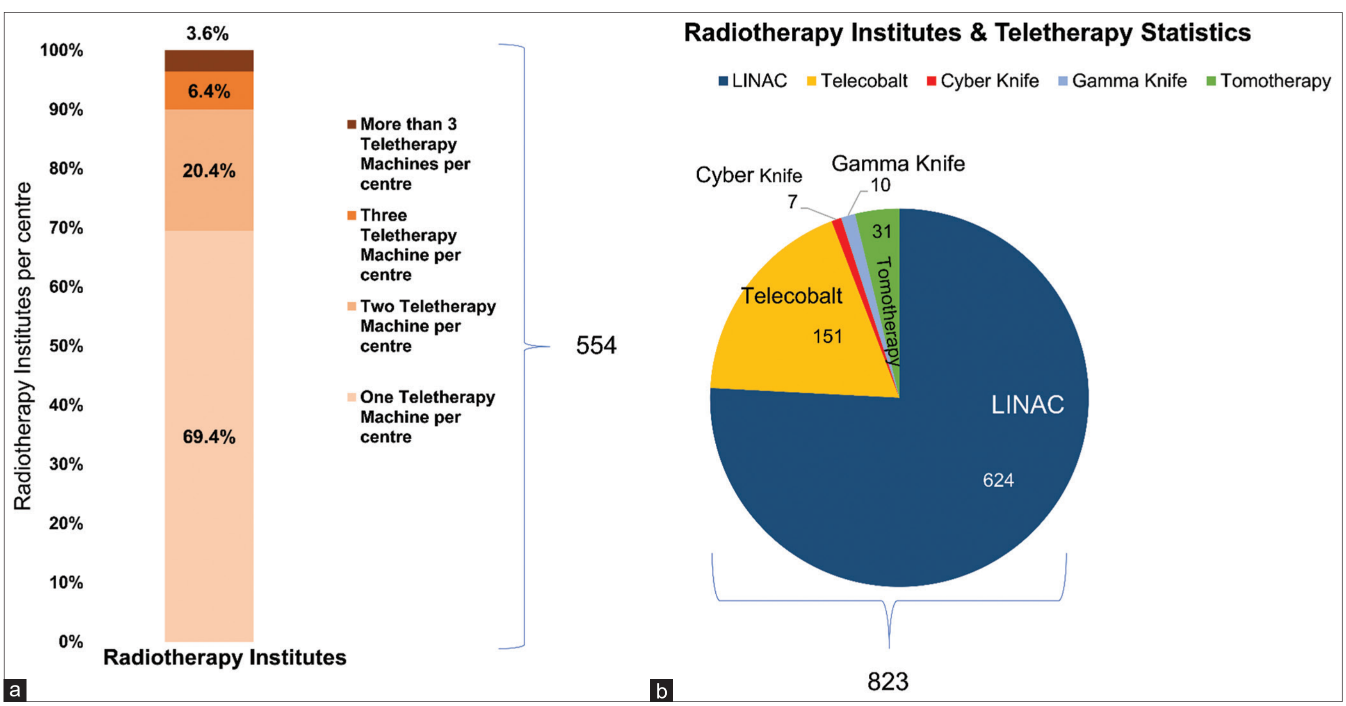


Figure 1: (a) Radiotherapy machines per institute in India and (b) statistics of different radiotherapy machines in 2022

Meghalaya, Arunachal Pradesh, and Sikkim have the least RTIs and RTMs.

Geographical distribution of linacs and telecobalt machines in the year 2022

Figures 5a and b depict the distribution of linacs and TC machines across the six geographical zones and 31 states and UTs of India. The southern zone has the most linacs (36.7%), while the northern zone has the most TC machines (31.0%). The state with the highest proportion of linacs is Maharashtra (13.8%), followed by Tamil Nadu (9.9%) and Gujarat (8.1%). In contrast, Uttar Pradesh has the highest proportion of TC machines (12%), followed by Maharashtra (11.4%) and Tamil Nadu (9.5%). Arunachal Pradesh has only one TC machine and no linac facility.

Radiotherapy machine density and shortage in India in 2022

In 2016, there were an estimated 1.34 million cancer patients in India.[16] This estimate translates to approximately 0.92 million RTP in India in the year 2022, as computed using equation (1). Consequently, this yields a projected demand of 2049 RTMs, calculated using equation,[2] which surpasses the current total of 823 RTMs as shown in Figure 1b by 1209 machines. The EP of India in the year 2022 was approximately 1371 million.[18,19] This leads to a projected RTM density (ETM/million) of 1.5, as determined by equation (3), and a current RTM density (CTM/million) of 0.6, calculated through equation (4). As shown in Table 2, the RTM density in six regions varies from 0.23 to 1.06 RTM/million. The Southern region has the highest RTM density (1.06 RTM/million), followed by the Western region (0.86 RTM/million) and lowest in the Eastern region (0.23 RTM/million).

Figure 6a is a map depicting the current RTM density (CTM/million) for 31 Indian states and UTs in 2022. The distribution of RTMs in various Indian states and UTs was found to be heterogeneous (0.08 RTM/million to 2.94 RTM/million). 29% of Indian states have less than 0.5 RTM/million, 38.7% have between 0.5 and 1 RTM/million, and 32.3% have greater than 1 RTM/million. Puducherry has the greatest RTM density (2.94 RTM/million), followed by Delhi (2.05 RTM/million), and Mizoram (1.63 RTM/million). The state with the lowest RTM density is Bihar (0.08 RTM/million), followed by Jharkhand (0.18 RTM/million) and Uttar Pradesh (0.25 RTM/million). The UTs of Puducherry and Delhi have surpassed the national estimated demand for RTMs, which stands at 1.5 RTM per million. Figure 6b and c depicts the ranking of regional zones, states, and territories based on population, total number of RTIs, RTMs, linacs, TC machines, RTP per million, current teletherapy density (CTM/million), and required teletherapy machines.

Additional radiotherapy machine requirement in India in the year 2022

Tables 2 and 3 present RT statistics and requirements for additional RTMs for six regional zones, 31 Indian states, and UTs. Among the six regional zones, the Northern zone requires the most additional RTMs (480), followed by the East zone with the second-highest demand for new RTM installations (335). Among the 31 states and UTs, Uttar Pradesh has the highest demand for RTMs (279), followed by West Bengal (114) and Bihar (113). In contrast, Delhi and Puducherry have three and two additional RTMs, respectively, to serve the populations of their respective states, ignoring the contribution of patients seeking treatment from other states and countries.

Impact of the COVID-19 pandemic on radiotherapy machine installations

The impact of a pandemic on RT installations in India is depicted in Figure 7. The pandemic appears to have had an impact on the teletherapy market, as the curve representing the number of installations has plateaued from 2019 to 2021 and is lower than the estimated values made assuming the pandemic did not occur [Figure 7a]. The RTM growth rate falls below 2% from expected 5% [Figure 7b]. Later, in 2022, the number of RTM installations increased to 823, indicating a market recovery for RTMs following the pandemic.

Discussion

According to our findings, the current status of teletherapy machines per million population in India stands at 0.6 RTM/

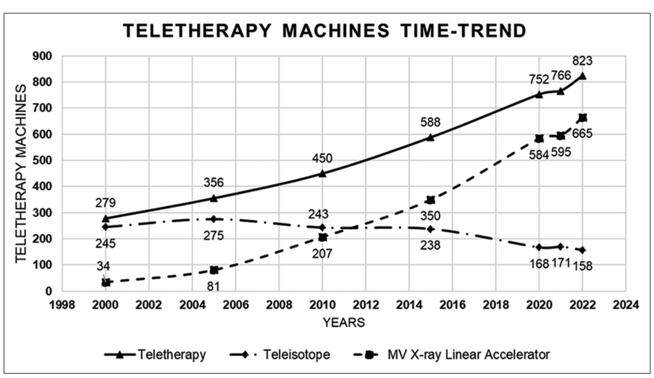


Figure 2: Radiotherapy machines, Telecobalt machines, and linac time trend from the year 2000 to the year 2022

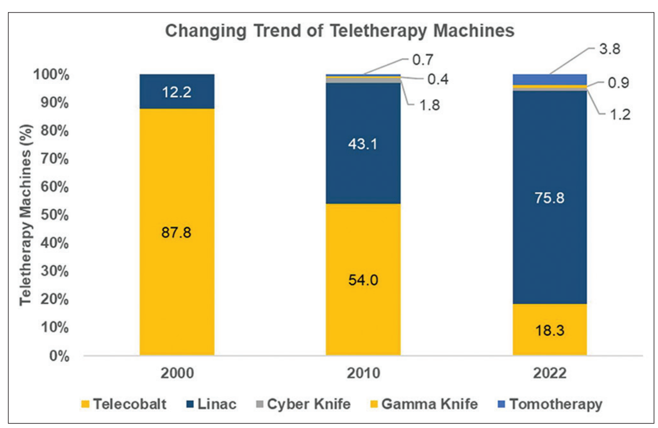


Figure 3: Changing trend of radiotherapy machines from telecobalt era to linac era in the last 22 years

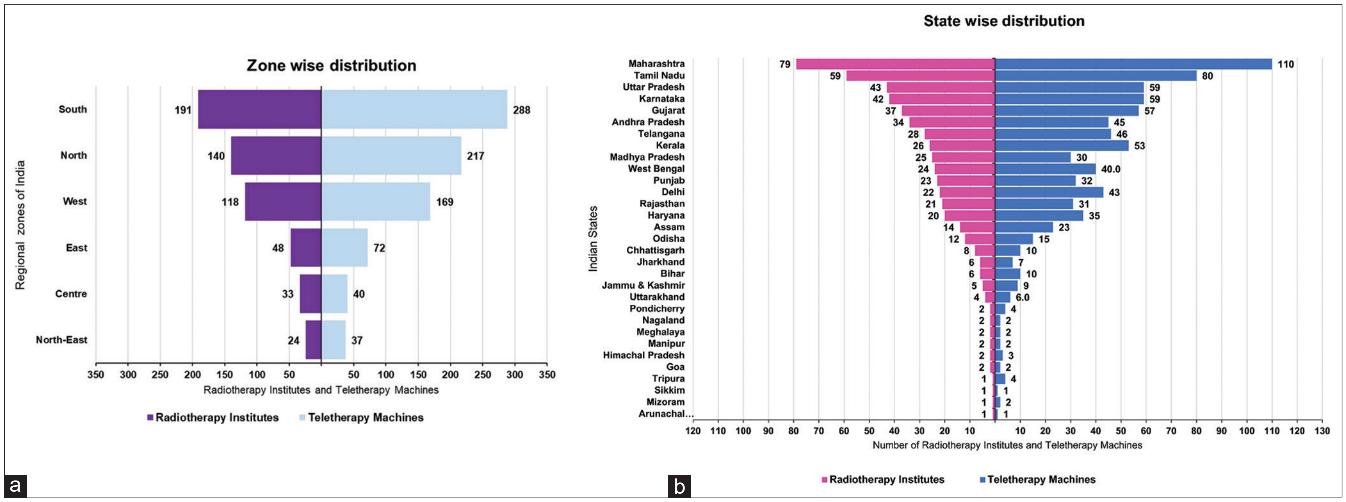


Figure 4: The current distribution of radiation institutions and radiotherapy machines across India's various (a) geographical zones and (b) 31 states and union territories

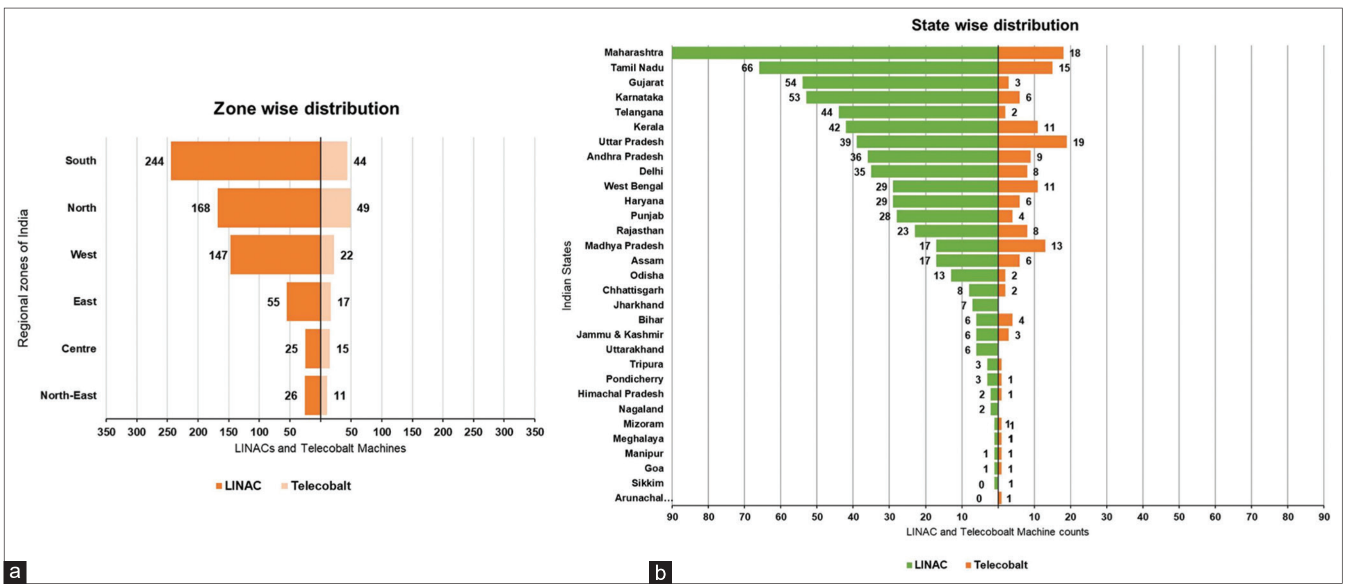


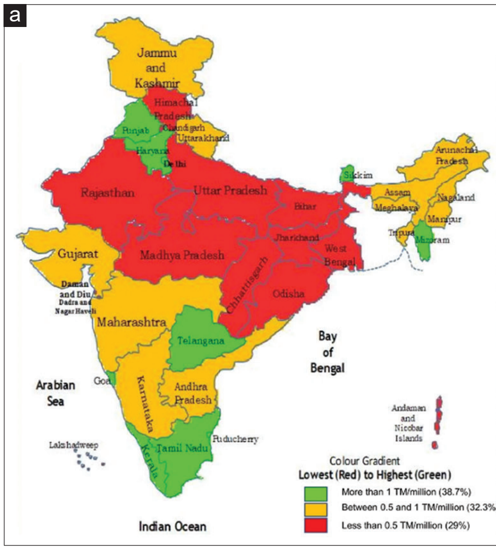
Figure 5: The distribution of linacs and telecobalt machines across India's various (a) geographical zones and (b) 31 states and union territories

Table 2: Radiotherapy machine statistics for six regional zones of India in the year 2022

Regional zones of India	EP (million)	NCI/ million	RTP/ million	ETM	ETM/ million	CTM	CTM/ million	Additional required teletherapy machines
North	428.8	1066	733	698	1.63	217	0.51	480
East	306.7	869	597	407	1.33	72	0.23	335
South	271.8	1113	765	462	1.70	288	1.06	175
West	197.6	1020	701	308	1.56	169	0.86	139
Centre	115.4	999	687	176	1.53	40	0.35	136
North-East	51.7	983	676	78	1.50	37	0.72	41

EP: Estimated population, NCI: New cancer incidence, RTP/million: Radiotherapy patients per million, ETM: Estimated teletherapy machines, CTM: Current teletherapy machines

million population in contrast to 4–12 RTM/million population in high-income countries.[23] There is currently a deficiency of RT infrastructure in the country, with a need for an additional 1209 RTMs. 70% of the RTIs have a single RTM, indicating that the majority of institutions have limited capacity to provide RT treatment, resulting in longer waiting times for patients and potentially reducing their access to timely treatment.[24-26] In the past two decades, linac installations have taken precedence, a



b

	Uttar Pradesh	Maharashtra	Bihar	West Bengal	Madhya Pradesh	Rajasthan	Tamil Nadu	Karnataka	Gujarat	Andhra Pradesh	Odisha	Telangana	Jharkhand	Assam	Kerala	Punjab
Population (in million)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Radiotherapy Institutes (RTIs)	3	1	18	10	9	13	2	5	4	6	16	19	7	8	15	11
Radiotherapy Machines (RTMs)	3	1	18	10	14	13	2	5	4	8	16	20	7	6	15	12
Linear Accelerators (LINACs)	7	1	19	10	14	13	2	3	4	8	16	18	5	6	15	12
Telecobalt Machines (TC)	1	2	14	6	4	9	3	15	10	7	18	28	17	5	12	13
Radiotherapy Patients per million	12	14	1	21	19	6	17	9	27	10	20	2	7	31	23	22
Radiotherapy Machines per million	29	13	31	23	26	25	9	16	14	15	27	30	7	4	18	10
Required Teletherapy Machines	31	26	29	30	28	27	21	23	25	17	24	22	11	19	20	15

	Chhattisgarh	Haryana	Delhi	Jammu & Kashmir	Uttarakhand	Himachal Pradesh	Tripura	Meghalaya	Manipur	Nagaland	Goa	Arunachal Pradesh	Puducherry	Mizoram	Sikkim
Population (in million)	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Radiotherapy Institutes (RTIs)	14	17	12	20	21	23	31	25	24	26	22	28	27	29	30
Radiotherapy Machines (RTMs)	11	17	9	19	21	24	23	27	26	28	25	30	22	29	31
Linear Accelerators (LINACs)	11	17	9	20	21	24	23	28	27	25	26	31	22	29	30
Telecobalt Machines (TC)	11	19	8	16	29	22	21	25	24	30	23	27	20	26	31
Radiotherapy Patients per million	29	16	28	13	24	25	4	15	3	5	26	11	18	30	8
Radiotherapy Machines per million	8	28	2	17	22	24	11	21	20	12	6	19	1	3	5
Required Teletherapy Machines	16	18	1	13	14	12	7	10	9	6	5	8	2	4	3

c

	North	East	South	West	Centre	North-East
Population (in million)	1	2	3	4	5	6
Radiotherapy Institutes (RTIs)	3	4	1	2	5	6
Radiotherapy Machines (RTMs)	2	4	1	3	5	6
Linear Accelerators (LINACs)	2	4	1	3	6	5
Telecobalt Machines (TC)	1	4	2	3	5	6
Radiotherapy Patients per million	2	6	1	3	4	5
Radiotherapy Machines per million	4	6	1	2	5	3
Required Teletherapy Machines	3	1	6	5	2	4

Figure 6: (a) Map representation of distribution of radiotherapy density in Indian states and union territories (UTs). States with more than 1 radiotherapy machine (RTM)/million population represented with green, states with RTM/million between 0.5 and 1 represented with orange, states with < 0.5 RTM/million population represented with red, (b) Indian states and UTs ranking shown as heat map. Each state has been given ranking from 1 to 31 for the listed parameters. (c) Regional zones ranking shown as heat map. Each zone has been given ranking from 1 to 6 for the listed parameters. Color gradient red to green indicates the regions of highest to lowest concern for the respective states and union territories

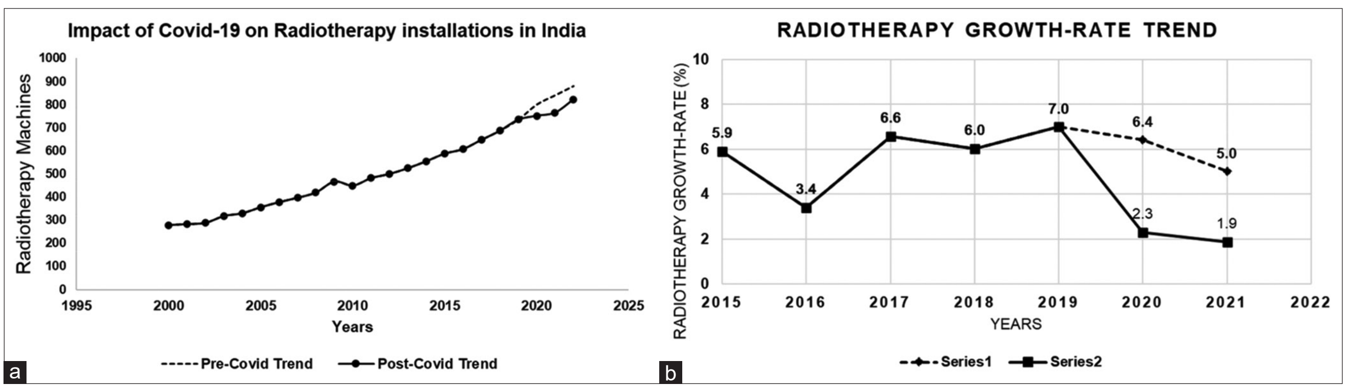


Figure 7: (a) Annual trend of radiotherapy machine installations from the year 2000 to 2022. Dotted line represents radiotherapy installations assuming no effect of pandemic. (b) Radiotherapy growth rate trend from the year 2015 to 2021. Dotted line indicates radiotherapy growth rate assuming no effect of pandemic

representing a paradigm shift toward the use of more advanced treatment techniques for improved patient outcomes.[27] In recent years, there is a growing interest in the installation of ring gantry-based linear accelerators, as the market share of Tomotherapy machines has increased from 0.7% in 2010 to 3.8% in 2022.[28-30]

The southern region of India has the highest proportion of RTIs (35%) and RTMs (34.5%), indicating that innovative policies have helped southern Indian states outperform the rest of the nation in terms of health and economic opportunities. Additionally, under India's decentralized approach to healthcare delivery, states are primarily responsible for organizing health services, so southern states may have developed their healthcare systems more successfully than other regions of India.[31,32] While the North-East region had the fewest installations of RTIs (4.5%) and RTMs (4.5%), this was primarily due to the region's hilly terrain, which makes it difficult to construct healthcare facilities there.[33] Compared to other Indian states, Maharashtra, Tamil Nadu, and Uttar Pradesh have the highest number of RTIs and RTMs, indicating a commitment to public health, which is reflected in the states' expenditure on public health report.[34]

We discovered substantial heterogeneity in RTM density across Indian states (0.08–2.94 RTM/million), with the result that 67% of Indian states lack even one RTM per million residents. The current RTM density is 0.6 RTM/million, whereas the current demand is 2.5 times greater. Only a few states, such as Puducherry and Delhi, perform better than the national average with more than two RTMs per million residents, and only three states have more than 1.5 RTMs per million residents. Delhi has an excess of two machines, exceeding the IAEA-recommended

Table 3: Teletherapy statistics for 31 Indian states and union territories in 2022

Indian states and UTs	EP (million)	NCI/ million	RTP/ million	ETM	ETM/ million	CTM	CTM/ million	Additional required teletherapy machines
Andhra Pradesh	53.0	927	632	74	1.40	45	0.85	29
Arunachal Pradesh	1.5	950	648	2.2	1.44	1	0.65	1
Assam	35.4	1091	744	59	1.65	23	0.65	36
Bihar	124.9	652	445	123	0.99	10	0.08	113
Chhattisgarh	29.8	992	677	45	1.50	10	0.34	35
Delhi	21.0	1245	849	40	1.89	43	2.05	-3
Goa	1.6	1174	800	2.8	1.78	2	1.28	1
Gujarat	70.6	917	625	98	1.39	57	0.81	41
Haryana	29.8	1250	852	57	1.89	35	1.17	22
Himachal Pradesh	7.4	1108	756	12	1.68	3	0.40	9
Jammu and Kashmir	13.8	958	653	20	1.45	9	0.65	11
Jharkhand	39.0	778	530	46	1.18	7	0.18	39
Karnataka	67.3	1229	838	125	1.86	59	0.88	66
Kerala	35.6	1637	1116	88	2.48	53	1.49	35
Madhya Pradesh	85.5	1006	686	130	1.52	30	0.35	100
Maharashtra	125.4	970	662	184	1.47	110	0.88	74
Manipur	3.2	778	530	4	1.18	2	0.63	2
Meghalaya	3.3	985	672	5	1.49	2	0.60	3
Mizoram	1.2	1473	1004	3	2.23	2	1.63	1
Nagaland	2.2	851	580	3	1.29	2	0.90	1
Odisha	44.2	1012	690	68	1.53	15	0.34	53
Puducherry	1.4	1003	684	2	1.52	4	2.94	-2
Punjab	31.8	1035	705	50	1.57	32	1.01	18
Rajasthan	80.2	878	599	107	1.33	31	0.39	76
Sikkim	0.7	900	614	1	1.36	1	1.46	0
Tamil Nadu	76.6	1003	684	116	1.52	80	1.04	36
Telangana	37.9	878	599	50	1.33	46	1.21	4
Tripura	4.1	835	569	5	1.27	4	0.97	1
Uttar Pradesh	233.3	956	652	338	1.45	59	0.25	279
Uttarakhand	11.5	1101	751	19	1.67	6	0.52	13
West Bengal	98.6	1033	705	154	1.57	40	0.41	114

EP: Estimated population, NCI: New cancer incidence, RTP/million: Radiotherapy patients per million, ETM: Estimated teletherapy machines, CTM: Current teletherapy machines, UTs: Union territories

ratio standards, in order to serve the local population.[35] This is likely due to its status as the nation's capital and the influx of individuals seeking quality healthcare from other states. Bihar, on the other hand, has the lowest density of teletherapy (0.08 RTM/million), followed by Jharkhand (0.18 RTM/million) and Odisha (0.25 RTM/million), which is attributed to very low per capita expenditure on public health by these states, resulting in a lack of healthcare facilities.[36] An additional 41.8% of RTMs are needed in just three Indian states: Uttar Pradesh (23%), Bihar (9.3%), and West Bengal (9.4%). This is because these states have a large population, resulting in a large pool of RTP.

In addition, we analyzed the influence of the COVID-19 pandemic on the RTM installation rate and found that the rate of increase for these installations has slowed since the current pandemic began in 2020. Contributing factors of reduction in installation rate can be the lockdown which impacted the import and export of equipment and RTMs, reduced hospital revenue, shift of institutional focus towards COVID-19 patient care and management.[37,38] Through financial packages, visionary initiatives, and other means, policymakers must focus on accelerating the current growth rate. As the epidemic is not yet over, it will be fascinating to observe how the growth rate evolves in the future.

The data presented in this study has its limitations as it is taken from various data sources. The unavailability of local, multi-centric, and institutional data has an impact on the robustness of the data presented in GLOBOCAN and ICMR reports as these reports are based on data registered under national and international cancer registries.[39-43] The IAEA's DIRAC database too is subjected to an update of RT resources by the voluntary participation of individual institutions and RTIs.[17] However, at our end, the RT data was updated by manually verifying from the institutions by adding some new institutes and removing some old institutes which either stopped RT or were closed. Worldometer population trend is based on % yearly change, fertility rate, migration, urban versus rural population, etc. These variables are subject to variation/correction and can only be verified by the nationwide census. ICMR reported cancer incidence data presented for 2016 was projected to 2022 based on the present yearly global cancer incidence rate which can vary from the actual incidence–rate. Also, national estimates can be significantly different from the global projected estimates.

Various researches have been conducted around the globe for analyzing the basic RT infrastructure, human resources, and staffing.[44-52] RT infrastructure and staffing analysis is the major requirement to assess the present load on RT facilities in the country. The lack of staffing in RT departments in India, particularly in the northern and eastern regions, poses a significant challenge to the development of RT infrastructure. This shortage of personnel, including radiation oncologists, medical physicists, radiation therapists, and other supporting staff, hampers the delivery of essential cancer care services.[49] At present, IAEA recommends at least one RTM per 450 cancer patients requiring RT per year.[22] However, actual infrastructure needs depend on the population structure of the country, cancer incidences, and treatment strategies used. Availability of RT services in the country also depends on various factors such as its economic status, political stability, gross domestic product per capita, and physician per capita.[7,53-58] Each country's RT utilization rate needs to be assessed and analyzed locally and at the national level.

This work is of critical importance in future policy planning for Indian cancer care and has its implications for global health as well. However, in future, this effort can also be extended to the other RT infrastructure present in the country by including statistics of brachytherapy and staffing of RT institutes. Further, classification and distribution of of RTMs on the basis of single-energy, dual-energy, or multi-energy linac models, different treatment techniques in different Indian states and UTs can be done in a future study.

Conclusions

This study, a first of its kind from India, indicates that there is a lack of RTMs in the country at the time of writing this paper with a shortage of 1209 machines in entire India. 81% of Indian states and UTs are below the required RTM/million indices. The ongoing pandemic has affected the RTM installation rate in the country. Our study establishes a clear need of improving the RT infrastructure distribution in most Indian states and UTs for the access of cancer patients and calls for increasing the RT installation rate.

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Conflicts of interest

There are no conflicts of interest.

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