1　吸収線量（率）計算方法の注意点

- HDR の吸収線量（率）計算方法の注意点は，LDR と同様であるため，詳細は LDR の「1 線量計算方式」を参照する．
- 2004 AAPM TG-43U1 に基づいた ^{60}Co, ^{192}Ir 及び ^{137}Cs の線量計算法が，AAPM と ESTRO から共同で報告[14)]されており，そちらも参考にすると良い．

2　治療装置，治療計画装置の受入試験

- 受入試験の項目を表 1 に示す
- 受入試験では装置の仕様書に沿った性能の有無や動作の確認を行い，精度や性能の評価はコミッショニングで行う．

表 1. 治療計画装置，治療装置の受入試験

項目	重要度
AT 1.　治療計画装置（線源と線量計算）	
AT 1.1.　線源情報の確認	A
AT 1.2.　線源の減衰	A
AT 1.3.　線源情報の登録	A
AT 1.4.　線量計算法（式）の理解	A
AT 1.5.　計算グリッドサイズによる線量分布への影響	A
AT 1.6.　アプリケータの再構成法	A
AT 1.7.　最適化計算法	A
AT 1.8.　DVH の計算方法と線量指標	A
AT 2.　治療計画装置（データベース）	
AT 2.1.　患者情報の登録と削除	A
AT 2.1.1.　2 人以上の同姓，同名又は同 ID 番号の登録	
AT 2.1.2.　同一患者の 2 度以上の登録	
AT 2.1.3.　患者データの削除	
AT 2.2.　バックアップとリストア	A
AT 3.　治療計画装置（画像入力とその利用）	
AT 3.1.　計画画像の登録	A
AT 3.1.1.　最大登録枚数	
AT 3.1.2.　不均一なスライス厚の画像登録の可否	
AT 3.2.　輪郭描出	A
AT 3.3.　自動マージン付加機能	A
AT 3.4.　レジストレーション（画像のフュージョン）	A

AT 4. 治療計画装置（ハードウェア，ネットワーク，その他）	
AT 4.1. ハードウェアの動作	A
AT 4.2. ネットワークや計画データの転送	A
AT 4.3. ハードコピー（プリントアウト）	A
AT 4.4. 計画装置のコンピュータの強制終了と復帰方法	A
AT 4.5. 操作説明書や解説書	A
AT 5. 治療装置（HDR 装置本体及びその制御装置）	
AT 5.1. 線源停止時間を決定するタイマの確認	A
AT 5.2. 線源情報の確認	A
AT 5.3. 線源停止位置精度	A
AT 5.4. 漏洩線量試験	A
AT 5.5. インターロックの作動条件と動作確認	A
AT 5.6. 停電，地震，火災などの緊急時の対応方法	A
AT 6. 付属機器	
AT 6.1. アプリケータの取扱	A
AT 6.2. 移送チューブの取扱	A
AT 6.3. その他の付属機器の取扱	A

3 治療計画装置のコミッショニング

- 治療計画装置のコミッショニングの項目を表 2 に示す.
- 表中で，介入レベルの列に示した"←"は，許容レベルと同値を指す.

表 2. 治療計画装置のコミッショニング

項目	許容レベル	介入レベル	重要度
C 1. 治療計画装置の試験（線量計算に関する項目）			
C 1.1. 点線量の計算精度	≤2%	> 5%	A
C 1.2. 等線量曲線の表示精度	性能評価	←	A
C 1.3. 計算グリッドサイズによる線量計算への影響	性能評価	←	A
C 1.4. 最適化計算の適応と特性	性能評価	←	A
C 1.5. アプリケータに付属する遮蔽器具の計算精度	性能評価	←	B
C 2. アプリケータリコンストラクションの方法と精度			
C 2.1. アプリケータの再構成方法	性能評価	←	A
C 2.2. アプリケータ内の線源停止位置	≤1 mm	> 2 mm	A

C 3.　治療計画画像の幾何学的精度			
C 3.1.　元画像と再構成画像の位置の整合性	性能評価	←	A
C 3.2.　治療計画画像の幾何学的精度（画像の縮小と拡大や歪み，など）	性能評価	←	A
C 4.　輪郭描出			
C 4.1.　体積の計算精度	性能評価	←	B
C 4.2.　輪郭描出方向による体積変化	性能評価	←	B
C 4.3.　自動マージン付加機能の動作	性能評価	←	B
C 4.4.　3 次元構造への拡張精度	性能評価	←	B
C 4.5.　領域が重複する輪郭の取扱	性能評価	←	B
C 4.6.　画像のレジストレーション	性能評価	←	B
C 5.　DVH の算出法			
C 5.1.　DVH と線量指標の計算精度	性能評価	←	B
C 5.2.　DVH 計算における輪郭の合算と減算	性能評価	←	B
C 5.3.　不均一なスライス厚を有する画像による体積の算出	性能評価	←	B
C 6.　リハーサル			
C 6.1.　End-to-end テスト	正常動作	←	A

4　治療計画装置の定期的品質管理

- 治療計画装置の定期的品質管理の項目を表 3 に示す.
- バージョンアップ時は，QC 5. に加えて，「3　治療計画装置」の表 2 に示すコミッショニングの項目も併せて行うことを推奨する.

表 3. 治療計画装置の定期的品質管理

試験内容	許容レベル	介入レベル	重要度
QC 1.　使用前			
QC 1.1.　ハードウェアの不具合やデータベースの簡便な確認	正常動作	←	A
QC 1.2.　単純な線量分布計算の不変性	≤3%	←	A
QC 1.3.　治療計画データの操作卓への転送	正常動作	←	A
QC 2.　1 か月ごと			
QC 2.1.　計画に関連するハードウェアの詳細な動作確認	正常動作	←	A
QC 2.2.　線源停止位置読取装置（デジタイザなど）の動作確認	正常動作	←	A

QC 3. 3か月ごと			
QC 3.1. 複雑な治療計画（複数線源，多チャンネル，最適化計算を使用）での不変性	≦3%	←	B
QC 3.2. イメージガイドに関する項目	各装置のQC項目を参照	←	A
3.2.1 CTやMRなど撮影装置の品質管理			
3.2.2 その他付属機器の品質管理			
QC 3.3. バックアップとリストア	正常動作	←	A
QC 3.4. プリンタや入力装置などの付属機器	正常動作	←	A
QC 4. 線源交換後			
QC 4.1. 登録した線源強度や校正日時などの線源情報	確認	←	A
QC 5. バージョンアップごと			
QC 5.1. 線源情報	確認	←	A
QC 5.2. DVHから算出した線量指標の不変性	≦3%	＞5 %	B
QC 5.3. 治療計画の再現性（End-to-endテスト）	≦5%	←	A

5 治療装置の定期的品質管理

- 治療装置の日常点検の項目を表4に，定期的品質管理の項目を表5に示す．（注）のマークのある項目は，機器の故障や重大な事故に繋がることがあるため，実施の可否や方法について，あらかじめメーカーと協議を必要とする．

表4. 治療装置の日常点検

試験内容	許容レベル	介入レベル	重要度
QC 1. 電源投入時			
QC 1.1. セルフテストの正常終了	正常動作	←	A
QC 1.2. 時刻や線源強度などの表示項目	正常動作	←	A
QC 1.3. 電子カルテやRISなどのネットワーク関連機器との接続	正常動作	←	A
QC 1.4. 患者監視カメラと通話装置の動作	正常動作	←	A
QC 1.5. 工具などの緊急用備品の有無とサーベイメータの動作	正常動作	←	A
QC 1.6. 照射室の使用中ランプの点灯	正常動作	←	A
QC 2. テスト照射設定時			
QC 2.1. HDR装置の破損有無	異常なし	←	A
QC 2.2. 移送チューブの捻れ，破損有無	異常なし	←	A

QC 3. テスト照射時			
QC 3.1. ドアインターロック	正常動作	←	A
QC 3.2. エリアモニタの動作	正常動作	←	A
QC 3.3. 簡易的な線源停止位置精度	≤ 1 mm	> 2 mm	A
QC 3.4. 照射室と操作卓の照射中ランプの点灯	正常動作	←	A
QC 3.5. タイマによる照射終了	正常動作	←	A
QC 4. テスト照射終了後			
QC 4.1. 照射室と操作卓の照射中ランプの消灯，線源収納	正常動作	←	A
QC 4.2. 治療システムの異常有無	正常動作	←	A

表 5. 治療装置の定期的品質管理

項目	許容レベル	介入レベル	重要度
QC 5. 3 か月ごと			
QC 5.1. 非常用バッテリの動作	正常動作	←	A
QC 5.2. HDR 装置と移送チューブ間の接続インターロックの動作	正常動作	←	A
QC 5.3. 治療中断ボタンの作動と再開	正常動作	←	A
QC 5.4. 緊急停止ボタンの作動と再開（注）	正常動作	←	A
QC 5.5. アプリケータの閉塞による線源引き戻し試験（注）	正常動作	←	A
QC 5.6. 水没試験によるアプリケータの気密性	異常なし	←	B
QC 6. 線源交換ごと又は 6 か月ごと（いずれか短い期間）			
QC 6.1. 電離箱による線源強度測定（線源仕様書との相違）	≤ 3.0%	> 5.0%	A
QC 6.2. 簡易的な HDR 装置からの漏れ線量測定	異常なし	←	A
QC 6.3. 線源停止位置精度の詳細な評価	≤ 1 mm	> 2 mm	A
QC 6.4. 手動線源引き戻し機構の動作	正常動作	←	A
QC 6.5. 線源位置移動時間の不変性（タイマの端効果）	≤ 10%	≧20%	A
QC 6.6. タイマの時間精度	≤ 1%	←	A
QC 7. 6 か月ごと			
QC 7.1. 直腸，膀胱用線量計の校正と記録	-	-	B
QC 8. 1 年ごと			
QC 8.1. 緊急時対応のスタッフトレーニング	-	-	A
QC 8.2. 詳細な HDR 装置からの漏れ線量測定	異常なし	-	A
QC 8.3. 移送チューブの寸法測定	≤ 1 mm	> 1 mm	A
QC 8.4. チェックケーブルやアプリケータなどの放射能汚染検査	汚染なし	←	A
QC 8.5. 線源駆動部やセンサなどの異常の有無（注）	異常なし	←	A
QC 8.6. システムの配線，コネクタの緩みや亀裂などの異常の有無	異常なし	←	A
QC 8.7. コンピュータウイルスのチェック（注）	異常なし	←	A
QC 8.8. エラーのログ解析	異常なし	←	A

6　患者治療ごとの品質保証

- 患者治療ごとの品質保証は，正当性の評価，動作確認及び異常の有無などの確認を行うため，性能評価を行わない．よって，許容レベルや介入レベルを設定しない．
- 患者治療ごとの品質保証は，計画担当者だけでなく，担当者以外の第三者により行われることが望ましい．

表 6. 患者治療ごとの品質保証

Pt 1.　治療計画装置で行う確認事項	重要度
Pt 1.1.　患者の同定	A
1.1.1.　患者名や ID 番号などによる治療患者と計画患者の同定	
1.1.2.　使用しているアプリケータの種類や本数	
Pt 1.2.　治療計画手順	A
1.2.1.　治療計画装置に登録する画像データが，対象患者，対象撮影日である	
1.2.2.　選択した線源データファイルの正当性(線源交換日,半減期による線源強度の減衰)	
1.2.3.　再構成したアプリケータの整合性と模擬線源の位置	
1.2.4.　ステップサイズ，カテーテルの長さ，オフセット値，及び線源停止位置	
1.2.5.　マンチェスター法やパリ法などに基づいた線量評価点の選択	
1.2.6.　線源遮蔽器具（Shielding）や他の補正係数の正当性	
1.2.7.　表示される単位の正当性	
1.2.8.　医師の指示又はアプリケータの幾何学的配置を考慮した，線量処方の定義や最適化方法の選択	
1.2.9.　処方線量と分割回数	
Pt 1.3.　線量分布	A
1.3.1.　ターゲットへの線量集中性や均一性	
1.3.2.　リスク臓器の線量，ホットスポットの有無と場所，線量制約の達成	
1.3.3.　線量基準点や線量評価点の位置や正当性	
1.3.4.　基準となる治療計画や対象患者の前回照射データとの比較と再現性	
Pt 2.　照射前の確認事項	
Pt 2.1.　ID 番号や氏名の確認による治療患者の同定	A
Pt 2.2.　使用アプリケータの種類（シリンダー直径，タンデムの角度など）	A
Pt 2.3.　線量評価点（A 点，基底線量点など）の位置	A
Pt 2.4.　計画装置から転送されたファイル名	A
Pt 2.5.　処方線量と分割回数	A
Pt 2.6.　第 3 者による治療計画の確認と独立検証	A
Pt 2.7.　計画装置で算出した照射時間とコンソールの照射時間の一致	A
Pt 2.8.　HDR 装置,移送チューブ,アプリケータを治療計画で設定したインデクサ番号に接続	A
Pt 2.9.　チェックケーブルによるテストランの正常終了の確認	A

Pt 3. 照射時の確認事項	
Pt 3.1. エリアモニタの指示値	A
Pt 3.2. 監視モニタによる患者の状態観察や装置の監視	A
Pt 3.3. 目視による線源の正常駆動	A
Pt 4. 治療終了後の処理，記帳，記録	
Pt 4.1. エリアモニタ及び目視による線源の格納確認	A
Pt 4.2. 照射記録と治療計画で，乖離がないことを確認	A
Pt 4.3. 抜去したアプリケータや移送チューブの目視確認	A
Pt 4.4. 患者の入退出記録	A
Pt 4.5. 装置の異常，異音やその他気づいたことの記録	A

7 放射線防護

- 放射性同位元素等による放射線障害の防止に関する法律（以下，障害防止法）の放射性同位元素等使用許可証に記載された最大使用時間を超えて，HDR 装置を使用してはならない．
- その他，医療法や障害防止法など関連する法令に従い，安全管理に努める．

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ORIGINAL ARTICLE

Japanese structure survey of radiation oncology in 2009 with special reference to designated cancer care hospitals

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Abstract
Background The structure of radiation oncology in designated cancer care hospitals in Japan was surveyed in terms of equipment, personnel, patient load, and geographic distribution, and compared with the structure in other radiotherapy facilities and the previous survey.

Methods The Japanese Society for Therapeutic Radiology and Oncology surveyed the national structure of radiation oncology in 2009. The structures of 365 designated cancer care hospitals and 335 other radiotherapy facilities were compared.

Results Designated cancer care hospitals accounted for 50.0 % of all the radiotherapy facilities in Japan. The patterns of equipment and personnel in designated cancer

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care hospitals and the other radiotherapy facilities were, respectively, as follows: linear accelerators per facility: 1.4 and 1.0; dual-energy function: 78.6 and 61.3 %; three-dimensional conformal radiotherapy function: 88.5 and 70.0 %; intensity-modulated radiotherapy function: 51.6 and 25.3 %; annual number of patients per linear accelerator: 301.3 and 185.2; Ir-192 remote-controlled afterloading systems: 31.8 and 4.2 %; and average number of full-time equivalent radiation oncologists per facility: 1.8 and 0.8. Compared with the previous survey, the ownership ratio of equipment and personnel improved in both designated cancer care hospitals and the other radiotherapy facilities. Annual patient loads per full-time equivalent radiation oncologist in the designated cancer care hospitals and the other radiotherapy facilities were 225.5 and 247.6, respectively. These values exceeded the standard guidelines level of 200.

Conclusions The structure of radiation oncology in designated Japanese cancer care hospitals was more mature than that in the other radiotherapy facilities. There is still a shortage of personnel. The serious understaffing problem in radiation oncology should be corrected in the future.

Keywords Radiotherapy · Medical engineering · Epidemiology

Introduction

In Japan, the current utilization rate of radiotherapy (RT) for new cancer patients in Japan is only 27.7 % and surgery remains predominant [1]. This rate is very low when compared to those for western developed countries. The main reason for this is that there is not enough personnel, such as radiation oncologists (ROs), medical physicists (MPs), and radiotherapy technologists (RTTs) [2, 3]. The Cancer Control Act was implemented in 2007 in response to patients' urgent petitions to the Japanese government [4]. This law strongly advocates the promotion of RT and an increase in the number of ROs and MPs. At the same time, the Ministry of Health, Labour and Welfare began the accreditation of "designated cancer care hospitals (DCCHs)" with the aim of correcting regional differences in the quality of cancer care and strengthening cooperation among regional cancer care hospitals [5, 6]. The Japanese Society for Therapeutic Radiology and Oncology (JASTRO) has conducted national structure surveys of RT facilities in Japan every 2 years since 1990 [7]. Findings of these surveys indicate that the structure of radiation oncology in Japan has improved in terms of equipment and functioning in response to the increasing numbers of cancer patients who require RT.

In the study presented here, the structure of radiation oncology in DCCHs in Japan was analyzed in terms of equipment, personnel, patient load, and geographic distribution, and compared with these features in other RT facilities in Japan. In addition, the recent structure of RT facilities was compared with that surveyed in 2007 [2] and the medical care situation in Japan was compared with that in European countries and the USA.

Methods and materials

A national survey in the form of a questionnaire on the structure of radiation oncology in Japan in 2009 was conducted by JASTRO from March 2010 to January 2011 [1]. The questionnaire consisted of items related to the number of treatment machines and type of modality, the number of personnel by job category, and the number of patients by type and disease site. The response rate was 90.9 % (700 out of 770) from all actual RT facilities in Japan. The number of DCCHs certified by the Ministry of Health, Labor and Welfare was 375 as of April 1, 2011 [8]. Of this total, 51 were designated prefectural and 324 were designated regional cancer care hospitals. The surveys were not returned by 20 facilities, and 3 facilities did not have departments of RT at the time of the survey, so that the structures of 365 DCCHs and 335 other RT facilities were analyzed. In this survey, full-time equivalent (FTE) (40 h/week for radiation oncology work only) data were surveyed in terms of the clinical working hours for RT of each staff member. SAS® 8.02 (SAS Institute Inc., Cary, NC, USA) [9] was used for the statistical analysis and statistical significance was determined by means of the χ^2 test and Student's t test.

The Japanese Blue Book Guidelines (JBBG) [10, 11] were used for comparison with the results of this study. These guidelines pertain to the structure of radiation oncology in Japan based on Patterns of Care Study (PCS) [12, 13] data. The standard guidelines for annual patient load per external beam equipment were set at 250–300 (warning level 400), those for annual patient load per FTE RO at 200 (warning level 300), and those for annual patient load per FTE RT technologists at 120 (warning level 200).

Results

Current situation of radiation oncology

Table 1 shows the current situation of radiation oncology in Japan. DCCHs accounted for 50.0 % (385/770) of all the RT facilities in Japan. The numbers of new patients and total patients in all RT facilities in Japan were estimated at approximately 201,000 (182,390 × 770/700) and 240,000 (205,087 × 770/700), respectively. For DCCHs,

Table 1 Numbers of new patients and total patients (new plus repeat) requiring radiotherapy in designated cancer care hospitals and other radiotherapy hospitals

	DCCHs	Other RT facilities	*p* value (95 % CI)[a]	Total
Facilities	365	335	–	700
New patients	126,123[b]	56,267	–	182,390[c]
Average new patients/facility	345.5	168.0	<0.0001 (146.7, 208.4)	260.6
Total patients (new + repeat)	150,215[b]	67,614	–	217,829[c]
Average total patients per facility	411.5	201.8	<0.0001 (171.6, 247.8)	311.2

DCCH designated cancer care hospital, *RT* radiotherapy, *CI* confidence interval

[a] Student's *t* test

[b] The number of designated cancer care hospitals with RT was 385, and the number of new patients in DCCHs was estimated at approximately 134,000; the corresponding number of total patients (new plus repeat) was 159,000

[c] The number of radiotherapy facilities was 770 in 2009, and the number of new patients was estimated at approximately 201,000; the corresponding number of total patients (new plus repeat) was 240,000

the corresponding numbers were approximately 134,000 (126,123 × 385/365) and 159,000 (150,215 × 385/365). The number of new patients and total patients in DCCHs thus accounted for approximately 66.7 % (134,000/201,000) and 66.3 % (134,000/201,000 and 159,000/240,000) of the number of new patients and total patients in all RT facilities. The average numbers of new patients per facility were 345.5 for DCCHs and 168.0 for the other RT facilities, and for the average numbers of total patients per facility the corresponding figures were 411.5 and 201.8, respectively.

Facility and equipment patterns and patient load per linear accelerator

The RT equipment patterns and related functions in Japan are shown in Table 2. In DCCHs, 496 linear accelerators (linacs) and 116 ^{192}Ir remote-controlled after-loading systems (RALSs) were in current use, while the corresponding data for the other RT facilities were 320 and 14, respectively. The rate of equipment ownership at DCCHs was significantly higher than at the other RT facilities. As for the linac systems in DCCHs, the dual-energy function was used in 390 (78.6 %), the three-dimensional conformal radiotherapy (3D-CRT) function in 439 (88.5 %), and the IMRT function in 256 (51.6 %). For the other RT facilities, the corresponding figures were 196 (61.3 %), 224 (70.0 %), and 81 (25.3 %). The patient load per linac was 301.3 at DCCHs and 185.2 at the other RT facilities. Compared with the data for DCCHs in 2007 [2], the rate of linac ownership increased by 0.6 % while the rates of increase for installation of the various functions used with linacs were 3.8 % for dual-energy, 13.2 % for 3D-CRT, and 15.2 % for IMRT function. At the other RT facilities, the rate of linac ownership decreased by 0.4 %, while the rates of installation corresponding to those for DCCHs increased by 4.8, 9.5, and 5.5 %. The patterns for radiotherapy planning systems (RTPs) and other equipment are shown in Table 2. X-ray simulators were installed in 56.7 %, computed tomography (CT) simulators in 83.3 %, and RTPs in 97.3 % of the DCCHs, while the corresponding percentages for the other RT facilities were 44.2, 70.4, and 94.6 %. A noteworthy difference between the two types of facilities was found in the rates of X-ray simulator and CT simulator installation. Compared with the data for 2007 [3], X-ray simulator ownership at DCCHs decreased by 12.6 %, while CT simulator and RTP ownership increased by 8.2 and 0.5 %, respectively. At the other RT facilities, X-ray simulator ownership decreased by 8.8 % while CT simulator and RTP ownership increased by 13.7 and 0.8 %, respectively.

The distribution of annual patient load per linac in Japan is shown in Fig. 1. The patient load at 19.4 % of DCCHs and 4.6 % of the other RT hospitals exceeded the JBBG warning level of 400 patients per linac, but the average patient load per linac at the other facilities was below that level. Compared with the data for 2007 [2], the rate of facilities exceeding the JBBG warning level (400 patients per linac) decreased at both DCCHs (−0.8 %) and the other RT facilities (−0.7 %). However, the average number of total patients per facility increased at both DCCHs (1.6 %) and the other RT facilities (5.9 %).

Staffing patterns and patient loads

Staffing patterns and patient loads in Japan are detailed in Table 3. The figures for total FTE ROs were 666.3 for DCCHs and 273.1 for the other RT facilities, while the corresponding average numbers of FTE ROs per facility were 1.8 and 0.8 and for patient load per FTE RO 225.5 and 247.6. The distribution of annual patient load per FTE RO in Japan is illustrated in Fig. 2. More than 300 patients per RO (JBBG warning level) were treated in 23.3 % of DCCHs and in 10.7 % of the other facilities. Figure 3 shows the distribution of facilities by patient load per FTE RO, with the largest number featuring a patient per FTE RO level in the 100–149 range for DCCHs and the other

Table 2 Items of equipment, their function and patient load per unit of equipment in designated cancer care hospitals and other radiotherapy hospitals

	DCCHs ($n = 365$)		Comparison with 2007	Other RT facilities ($n = 335$)		Comparison with 2007	p value (95 % CI)	Total ($n = 700$)	
	n	%	%	n	%	%		n	%
Linac	496	98.6[a]	0.6[c]	320	90.4[a]	−0.4[c]	<0.0001[f]	816	94.7[a]
With dual energy function	390	78.6[b]	3.8[c]	196	61.3[b]	4.8[c]	<0.0001[f]	586	71.8[b]
With 3D-CRT function (MLC width ≤1.0 cm)	439	88.5[b]	13.2[c]	224	70.0[b]	9.5[c]	<0.0001[f]	663	81.3[b]
With IMRT function	256	51.6[b]	15.2[c]	81	25.3[b]	5.5[c]	<0.0001[f]	337	41.3[b]
Average no. linac per facility	1.4	–	4.7[e]	1.0	–	0.4[e]	<0.0001 (0.3, 0.4)[g]	1.2	–
Annual no. patients per linac	301.3[d]	–	1.6[e]	185.2[d]	–	5.9[e]	<0.0001 (86.8, 133.9)[g]	255.8[d]	–
^{192}Ir RALS (actual use)	116	31.8[a]	2.3[c]	14	4.2[a]	−1.2[c]	<0.0001[f]	130	18.6[a]
X-ray simulator	211	56.7[a]	−12.6[c]	150	44.2[a]	−8.8[c]	0.0009[f]	361	50.7[a]
CT simulator	324	83.3[a]	8.2[c]	251	70.4[a]	13.7[c]	<0.0001[f]	575	77.1[a]
RTP computer	854	97.3[a]	0.4[c]	417	94.6[a]	0.8[c]	0.0757[f]	1,271	96.0[a]

DCCH designated cancer care hospital, *RT* radiotherapy, *CI* confidence interval, *Linac* linear accelerator, *IMRT* intensity-modulated radiotherapy, *RALS* remote-controlled after-loading system, *CT* computed tomography, *3D-CRT* three-dimensional conformal radiotherapy, *RTP* radiotherapy planning

[a] Percentage of facilities which have this equipment

[b] Percentage calculated from the number of systems using this function and the total number of linac systems

[c] Comparison with the data of 2007, calculated using the formula: data of 2009 (%) − data of 2007 (%)

[d] Percentage calculated from the number of patients and the number of linac units. Facilities without linacs were excluded from the calculation

[e] Rate of increase compared with the data of 2007, calculated using the formula: $\frac{\text{data of 2009 }(n) - \text{data of 2007 }(n)}{\text{data of 2007 }(n)} \times 100$ (%)

[f] χ^2 test

[g] Student's t test

RT facilities. Facilities with less than 1 FTE RO still account for about 31.2 % of DCCHs and 65.7 % of the other RT facilities. The average numbers of FTE ROs per facility and full-time JASTRO-certified ROs per facility at DCCHs increased by 11.5 and 6.7 %, respectively, compared with 2007 data, and for the other RT facilities, those numbers increased by 18.9 and 22.3 %. The annual patient load per FTE RO, on the other hand, decreased by 4.9 % at DCCHs and 9.4 % at the other RT facilities.

The total numbers of FTE RTTs were 1175.7 for DCCHs and 660.2 for the other RT facilities, and the corresponding average numbers of RTTs per facility were 3.2 and 2.0, while the patient loads per FTE RTT were 127.8 and 102.4. The distribution of annual patient load per FTE RTT in Japan is shown in Fig. 4. More than 200 patients per RTT (JBBG warning level) were treated in 11.0 % of DCCHs and in 7.5 % of the other RT facilities, while Fig. 5 shows the distribution of facilities by patient load per FTE RTT. The largest number of facilities featured a patient per FTE RTT level in the 100–119 range for DCCHs and the other RT facilities. The total numbers of FTE MPs and FTE RT nurses were 74.6 and 392.8, respectively, for DCCHs and 43.0 and 228.4 for the other RT facilities.

Distribution of primary disease sites and palliative treatment

Table 4 shows the distribution of primary disease sites and palliative treatment at DCCHs and the other RT facilities. The most common disease site at DCCHs and the other RT facilities was the breast. Head/neck, esophagus, liver/biliary tract/pancreas, gynecologic, urogenital, prostate, hematopoietic/lymphatic, and skin/bone/soft tissue cancers were treated at higher rates at DCCHs than at the other RT facilities. The rates for other cancers were the reverse. Compared with the data for 2007, the percentage of breast cancers increased the most at DCCHs (1.4 %), and at the other RT facilities the percentage of head/neck and breast cancers increased significantly (2.4 and 2.3 %).

Brain metastasis was treated at higher rates at the other RT facilities (14.7 % of total patients) than at DCCHs (6.9 % of total patients), while the reverse was true for

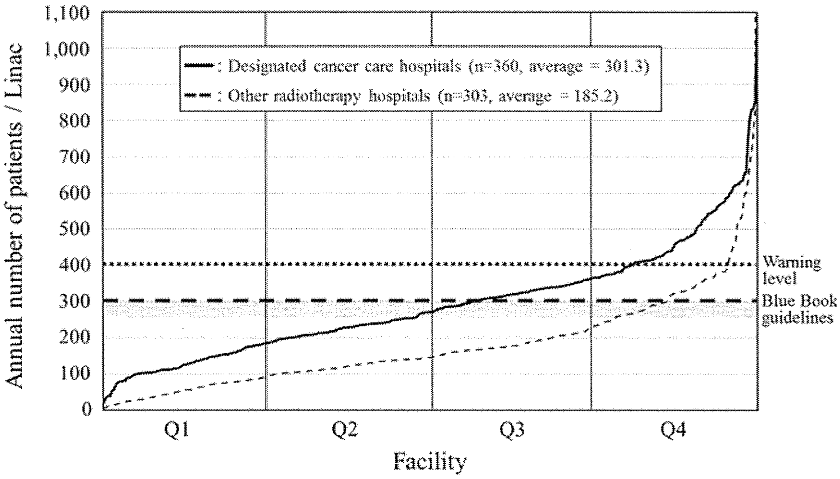


Fig. 1 Distribution of annual patient loads per linear accelerator in designated cancer care hospitals and the other radiotherapy facilities. *Horizontal axis* represents facilities arranged in order of increasing value of annual number of patients per treated equipment within facilities. *Q1* 0–25 %, *Q2* 26–50 %, *Q3* 51–75 %, *Q4* 76–100 %

Table 3 Structure and personnel of designated cancer care hospitals and other radiotherapy hospitals

	DCCHs ($n = 365$)	Comparison with 2007[a] (%)	Other RT facilities ($n = 335$)	Comparison with 2007[a] (%)	p value[b]	Total ($n = 700$)
Facilities with RT beds	190	–	108	–	–	298 (42.6)
Average no. RT beds per facility	4.2	−1.5	2.2	11.5	–	3.3
Total (full + part-time) RO FTE	666.3	–	273.1	–	–	939.4
Average no. FTE ROs per facility	1.8	11.5	0.8	18.9	<0.0001	1.3
JASTRO-certified RO (full-time)	422	–	109	–	–	531
Average no. JASTRO-certified ROs per facility	1.2	6.7	0.3	22.3	<0.0001	0.8
Annual no. patients per FTE RO	225.5	−4.9	247.6	−9.4	<0.0001	231.9
Total (full + part-time) RT technologist FTE	1175.7	–	660.2	–	–	1836.0
Average no. FTE RT technologists per facility	3.2	16.8	2.0	9.1	<0.0001	2.6
Annual no. patients per FTE RT technologist	127.8	−9.2	102.4	−1.3	<0.0001	118.7
Total (full + part-time) medical physicist FTE	74.6	77.7	43.0	62.9	–	117.6
Total (full + part-time) RT nurse FTE	392.8	29.1	228.4	20.1	–	621.2

DCCH designated cancer care hospital, *RT* radiotherapy, *RO* radiation oncologist, *FTE* full-time equivalent (40 h/week only for RT practise), *JASTRO* Japanese Society for Therapeutic Radiology and Oncology

[a] Rate of increase compared with the data of 2007, calculated using the formula: $\frac{\text{data of 2009 } (n) - \text{data of 2007 } (n)}{\text{data of 2007 } (n)} \times 100\ (\%)$

[b] Student's t test

bone metastasis (11.3 and 12.8 %, respectively). Compared with the data for 2007, the rate of brain and bone metastasis decreased in both DCCHs (−0.7 and −0.9 %) and the other RT facilities (−1.0 and −2.3 %).

Discussion

The utilization rate of RT for new cancer patients in Japan is less than half of that in developed countries in Europe and in the USA [14]. However, RT is expected to play an increasingly important role in Japan because the increase in the elderly population is the highest among developed countries. The distribution of facilities by patient load per RO for DCCHs proved to be largely similar to that of the USA in 1989 [15]. While the numbers of ROs in both DCCHs and the other RT hospitals in Japan has increased, the facilities which have less than one FTE RO still account for 31.2 % of DCCHs and 65.7 % of the other RT facilities. In Japan, the majority of facilities still rely on

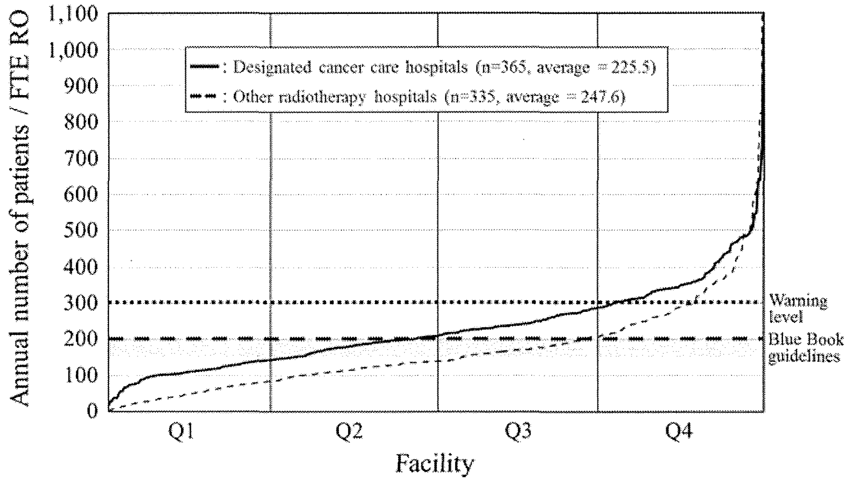


Fig. 2 Distribution of annual patient loads per FTE RO in designated cancer care hospitals and the other radiotherapy facilities. *Horizontal axis* represents facilities arranged in order of increasing value of annual number of patients per FTE RO within facilities. *Q1* 0–25 %, *Q2* 26–50 %, *Q3* 51–75 %, *Q4* 76–100 %. Number of FTE RO for facilities with FTE <1 was calculated as FTE = 1 to avoid overestimating patient loads per FTE RO

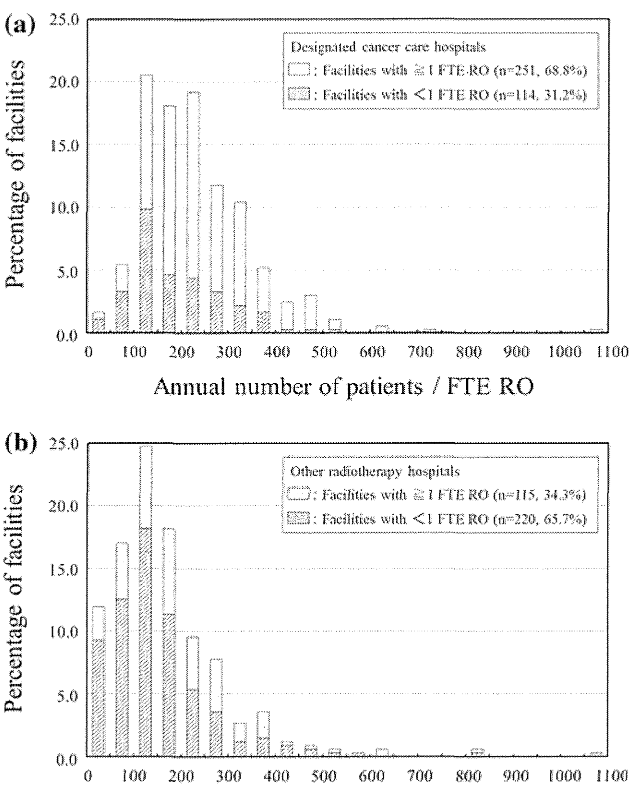


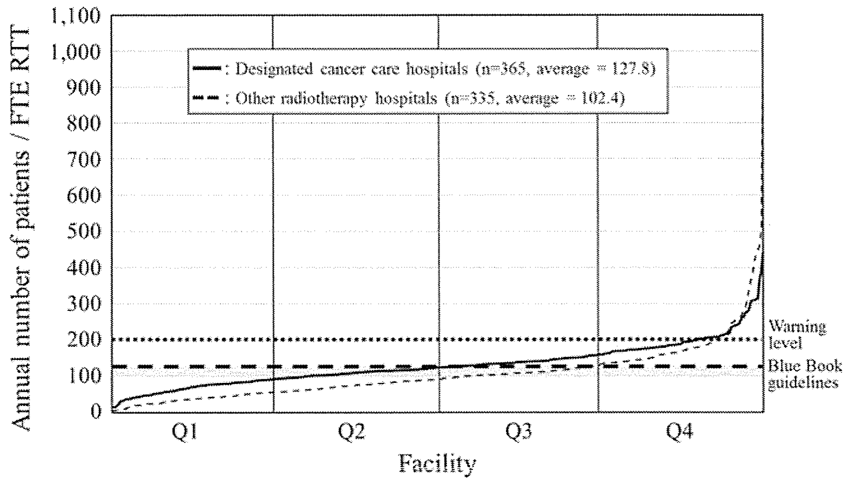
Fig. 3 Percentage of facilities by patient loads per FTE RO in designated cancer care hospitals (**a**) and in the other radiotherapy hospitals (**b**). *Each bar* represents an interval of 50 patients per FTE RO. Number of FTE RO for facilities with FTE <1 was calculated as FTE = 1 to avoid overestimating patient loads per FTE RO

part-time ROs, especially in facilities other than DCCHs, but in western developed countries, most facilities have at least 1 full-time RO. The distribution in Japan of facilities by patient load per RO for the other RT facilities in this study was similar to that in 1990 [15], so that a shortage of ROs has remained a major concern. More than 300 patients per RO (JBBG warning level) were treated in 17.6 % of all RT facilities. This is a matter of critical importance to the quality of radiotherapy.

A new educational system called "Cancer Professional Training Plan" by the Ministry of Education, Culture, Sports, Science and Technology, Japan is being developed in Japan to train specialists for cancer care, including ROs, MPs, medical oncologists, oncology nurses, and palliative care doctors. The average number of RT staff members at DCCHs was greater than that in the other RT hospitals. As noted above, there is still a shortage of Ros, although the numbers have increased. In Japan, many RT hospitals do not have an independent department for RT. One way to increase the number of ROs is to create an independent department for RT. The numbers of MPs in Japan are still smaller than those in western developed countries, and they work mainly in metropolitan areas or academic facilities, such as university hospitals or cancer centers. At present, no national license is available for MPs in Japan, but those with a master's degree in radiation technology or science and engineering can take the accreditation test for MPs administered by the Japanese Board of Medical Physics (JBMP). Compared with ROs and MPs, a sufficient number of RTTs is ensured in Japan. However, there is a significant number of hospitals with less than 1 FTE RTT in both DCCHs ($n = 13$) and the other RT hospitals ($n = 50$). In addition, many RTTs are extremely busy because they must also partially act as MPs. As for equipment, the ownership of equipment for advanced high-precision radiation therapy machines increased compared with 2007 at all RT facilities, especially DCCHs, indicating that the accreditation of DCCHs closely correlates with the maturity of the radiation oncology structure. Further accreditation of DCCHs by the Ministry of Health, Labor, and Welfare would be a move in the right direction towards a more balanced geographic consolidation of RT facilities in Japan.

The findings of this study show that, on a regional basis, DCCHs were located in the most suitable areas. There were

Fig. 4 Distribution of annual patient loads per FTE RTT in designated cancer care hospitals and the other radiotherapy facilities. *Horizontal axis* represents facilities arranged in order of increasing value of annual number of patients per FTE RTT within facilities. *Q1* 0–25 %, *Q2* 26–50 %, *Q3* 51–75 %, *Q4* 76–100 %. Number of FTE RTT for facilities with FTE <1 was calculated as FTE = 1 to avoid overestimating patient loads per FTE RTT



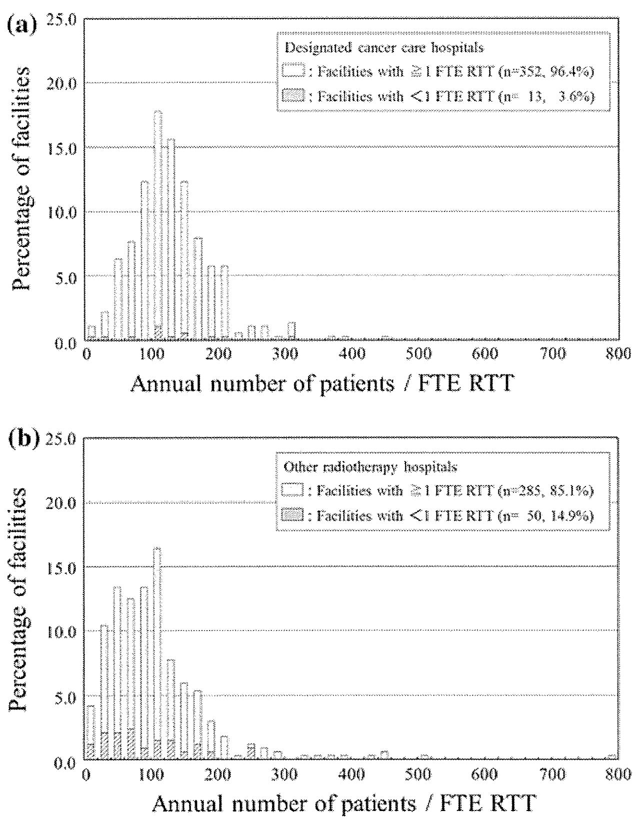


Fig. 5 Percentage of facilities by patient loads per FTE RTT in designated cancer care hospitals (**a**) and in the other radiotherapy hospitals (**b**). *Each bar* represents an interval of 20 patients per FTE RTT. Number of FTE RTT for facilities with FTE <1 was calculated as FTE = 1 to avoid overestimating patient loads per FTE RTT

388 DCCH facilities by the end of fiscal year 2011 because some further university facilities with many patients undergoing RT had been certified as DCCHs since the previous survey, while some small-scale facilities were not certified as DCCHs by the Ministry of Health, Labor, and Welfare. In terms of nationwide distribution, there seem to be enough RT facilities in Japan. On the other hand, the RT potential of RT facilities other than DCCHs in Japan remains unrealized because of personnel shortages. The most frequent primary disease site treated with RT at the other RT facilities changed from lung/trachea/mediastinum to breast, compared with the data for 2007, while at DCCHs, the most frequently treated primary disease site, the breast, remained unchanged from 2007. Finally, the number of patients with brain and bone metastasis did not increase since 2007.

To evaluate medical care systems for cancer at regular intervals, it is very important to collect detailed information on all cancer care facilities. In Japan, the structural data for all RT facilities is regularly surveyed by JASTRO. In addition, the procedures and the outcome data of cancer care for patients undergoing RT have been conducted by PCS every 4 years, but insufficient outcome data is collected. In the USA, a National Cancer Data Base was established in 1989 and since then has been collecting comprehensive data on cancer care, and this database is used as the quality indicator for improvements in the processes and outcomes of cancer care [16, 17]. We have established a Japanese National Cancer Database based on the RT data in Japan and we are preparing to use this system for the collection of cancer care data.

In conclusion, the RT structure of DCCHs in Japan showed more maturity than that of other RT facilities in terms of equipment, functions, and staff. However, there is still a shortage of personnel (ROs, RTTs, MPs, RT nurses, and so on) in radiation oncology in Japan. The structure survey data presented and discussed here seemed to be both fundamental and important for a clear and accurate understanding of the medical care system for radiation oncology in Japan. As this survey data makes clear, a

Table 4 Primary sites of cancer, brain metastasis, and bone metastasis treated with RT in designated cancer care hospitals and the other radiotherapy hospitals

Primary site	DCCHs (n = 344)		Comparison with 2007[a]	Others (n = 300)		Comparison with 2007[a]	p value[b]	Total (n = 644)	
	n	%	%	n	%	%		n	%
Cerebrospinal	4,719	3.9	0.2	4,342	8.5	−1.1	<0.0001	9,061	5.8
Head and neck (including thyroid)	13,084	10.9	−0.2	5,021	9.8	2.4	<0.0001	18,105	9.8
Esophagus	7,306	6.1	−0.4	2,288	4.5	−0.6	<0.0001	9,594	6.0
Lung, trachea, and mediastinum	21,600	18.0	−0.6	10,707	21.0	−0.5	<0.0001	32,307	19.5
Lung	19,532	16.2	−0.6	9,659	18.9	0.7	<0.0001	29,191	17.3
Breast	27,706	23.0	1.4	12,128	23.8	2.3	0.0008	39,834	21.5
Liver, biliary, tract, and pancreas	4,733	3.9	−0.1	1,908	3.7	0.3	0.0577	6,641	3.8
Gastric, small intestine, and colorectal	5,693	4.7	−0.2	2,586	5.1	−0.4	0.0029	8,279	5.1
Gynecologic	6,851	5.7	0.0	1,365	2.7	−0.6	<0.0001	8,216	4.9
Urogenital	16,641	13.8	0.7	6,409	12.6	−0.2	<0.0001	23,050	13.0
Prostate	12,830	10.7	0.9	5,089	10.0	0.6	<0.0001	17,919	9.6
Hematopoietic and lymphatic	6,176	5.1	−0.3	1,773	3.5	−0.1	<0.0001	7,949	4.8
Skin, bone, and soft tissue	3,014	2.5	−0.1	1,079	2.1	−0.7	<0.0001	4,093	2.7
Other (malignant)	1,359	1.1	−0.2	582	1.1	−0.3	0.8388	1,941	1.4
Benign tumors	1,407	1.2	−0.3	813	1.6	−0.4	<0.0001	2,220	1.6
Pediatric < 15 years (included in totals above)	900	0.7	0.0	192	0.4	−0.1	<0.0001	1,092	0.6
Total	120,289	100.0	0.0	51,001	100.0	0.0		171,290[c]	100.0
Metastasis	(n = 365)			(n = 335)				(n = 700)	
Brain	10,361	6.9	−0.7	9,973	14.7	−1.0	<0.0001	20,334	10.4
Bone	19,293	12.8	−0.9	7,613	11.3	−2.3	<0.0001	26,906	13.6

[a] Comparison with the data of 2007, calculated using the formula: data of 2009 (%) – data of 2007 (%)

[b] χ^2 test

[c] Number of total new patients is different with these data, because no data on primary sites were reported by some facilities

national policy is needed to improve the establishment of DCCHs and overcome the shortage of personnel for cancer care.

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Original Article

Survey of Advanced Radiation Technologies Used at Designated Cancer Care Hospitals in Japan

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Objective: Our survey assessed the use of advanced radiotherapy technologies at the designated cancer care hospitals in Japan, and we identified several issues to be addressed.
Methods: We collected the data of 397 designated cancer care hospitals, including information on staffing in the department of radiation oncology (e.g. radiation oncologists, medical physicists and radiation therapists), the number of linear accelerators and the implementation of advanced radiotherapy technologies from the Center for Cancer Control and Information Services of the National Cancer Center, Japan.
Results: Only 53% prefectural designated cancer care hospitals and 16% regional designated cancer care hospitals have implemented intensity-modulated radiotherapy for head and neck cancers, and 62% prefectural designated cancer care hospitals and 23% regional designated cancer care hospitals use intensity-modulated radiotherapy for prostate cancer. Seventy-four percent prefectural designated cancer care hospitals and 40% regional designated cancer care hospitals employ stereotactic body radiotherapy for lung cancer. Our multivariate analysis of prefectural designated cancer care hospitals which satisfy the institute's qualifications for advanced technologies revealed the number of radiation oncologists ($P = 0.01$) and that of radiation therapists ($P = 0.003$) were significantly correlated with the implementation of intensity-modulated radiotherapy for prostate cancer, and the number of radiation oncologists ($P = 0.02$) was correlated with the implementation of stereotactic body radiotherapy. There was a trend to correlate the number of medical physicists with the implementation of stereotactic body radiotherapy ($P = 0.07$). Only 175 (51%) regional designated cancer care hospitals satisfy the institute's qualification of stereotactic body radiotherapy and 76 (22%) satisfy that of intensity-modulated radiotherapy. Seventeen percent prefectural designated cancer care hospitals and 13% regional designated cancer care hospitals had a quality assurance committee.
Conclusions: The numbers of radiation oncologists and other operating staff might be essential factors in the implementation of advanced radiotherapy technologies. Small proportions of regional designated cancer care hospitals satisfy the institute's qualifications of advanced technologies.

Key words: radiotherapy – stereotactic body radiotherapy – intensity-modulated radiotherapy – advanced radiotherapy technology