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Original Article

Evaluation of the user-friendliness and dosimetric accuracy of treatment planning systems for 3-dimensional conformal radiotherapy

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Abstract

Purpose: The purpose of this study is to compare the performance of three 3-dimensional radiotherapy treatment planning systems (TPS) in terms of user-friendliness and dosimetric accuracy.

Methods: A scale type questionnaire, which contained 129 items under 13 aspects of the TPS, was used to collect opinions from users from three different institutions with regards to the user-friendliness. The assessment of dosimetric accuracy was carried out by comparing the measured dose values with those calculated by the TPS under 18 different irradiating and phantom set-up conditions.

Results: Eleven respondents completed the questionnaires for each TPS. Our study indicated that the Varian CadPlan was outstanding in the plotting and network transfer of treatment plans to other workstations, the CMS Focus performed better in the construction of treatment aids, and the ADAC Pinnacle in the outlining, modification of field parameters, control of graphics and normalization of dose. In terms of dosimetric accuracy, the measured and the calculated data for the 3 TPSs showed fairly good agreement. Except for the field with median block, in which the Focus presented with the best result, the differences in other irradiating conditions were not obvious with the percentage dose deviations within ±3%.

Conclusion: In conclusion, for the 3 TPSs evaluated, each had its own strengths and weaknesses, and no TPS was superior in all test conditions.

Keywords

Radiotherapy planning; dose measurement; questionnaires; phantom

INTRODUCTION

Recent advances in equipment technology have facilitated the development and implementation of 3-dimensional conformal radiotherapy (3DCRT) treatment. The merits of 3DCRT as compared to the conventional 2-dimensional treatment have been documented in numerous papers that included dosimetric studies and clinical trials of various malignant diseases.[1–4] The development of the sophisticated TPS is one of the crucial factors that have paved the way to this new treatment modality. Today, a variety of high-end 3-D computer treatment planning systems are available in the market. Despite the fact that all TPS are designed to perform the same task, i.e. to maximise the target to normal tissue dose ratio, they are different from each other in terms of system design, operation procedures, planning tools and features, and dose calculation algorithms. Before

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making the decision to purchase a suitable TPS and set-up the optimum treatment planning routines in individual departments, it is important to understand the strengths and weaknesses of individual models. The considerations include dose accuracy, capability and the user-friendliness of the planning systems. A highly accurate planning system with sophisticated 3-D planning capability provides accurate prediction and display of dose distribution in patients and makes complicated treatment techniques possible, which in turn improves treatment results. User-friendly systems enhance the efficiency of radiotherapy treatment planning and thus reduce the staff operation time, which accounts for the departmental cost. To ensure the best selection, the evaluation of the user-friendliness and dosimetric accuracy for the TPS is necessary.

Rosemark et al.[5] studied 7 TPS's with regards to their facilities. However, the performance information was supplied by the vendors and not confirmed by the authors. The aim of this study was to conduct an objective evaluation on the user-friendliness and dosimetric accuracy of three commonly used models of TPSs with 3-D facilities based on their user-friendliness and dosimetric accuracy. The three systems under evaluation were the ADAC Pinnacle (Version 5.2g), Varian CadPlan (Version 6.08) and CMS Focus (Version 2.50). The Pinnacle was operated on the Sun Ultra 2 workstation whereas the CadPlan and Focus were using the HPC200 workstation. At the time of study, there were 3 CadPlans, 2 Pinnacles and 1 Focus systems utilised in six different institutions in Hong Kong.

The data collected and the conclusion presented in this report may serve as useful references for end user departments in the acquisition of a TPS that can best suit their specific needs. Nevertheless, readers should note that the performance data collected in this study is only valid for the hardware and software versions indicated above. They are subject to change with software and hardware upgrades after this study.

METHODS AND MATERIALS

User-friendliness

A survey was conducted to collect the opinions from radiographers and medical physicists, who were the frequent users of radiotherapy TPS in their departments and had a minimum of 2 years working experience on the system. A questionnaire was designed and used to collect the required information. It was designed with reference to the criteria suggested by Harm et al.,[6] who introduced a range of guidelines for the evaluation of commercially available 3-D TPSs. A draft questionnaire was first tested and completed by 5 frequent users of TPS, and modifications were then made according to their comments on the clarity and structure of the statements. The final version of the questionnaire contained a total of 129 items that covered 13 aspects of the TPS operation (Table 1). For each item in the questionnaire, the respondents were asked to give a point score from 0–5 to reflect their opinions. The target number of respondents for each system was 10–15.

Table 1. *Various aspects included in the survey of user-friendliness of the three TPS*

Various aspects of TPS	Number of items
CT/MRI image transfer	4
Outlining and structure delineation	13
Construction of treatment field	14
Construction of treatment aids	8
Modification of field parameters	21
Evaluation of treatment plans	13
Control of graphics	21
Normalization of dose	3
Dose calculation	4
MU calculation	3
DRR generation	4
Plan output	7
System administration	14
Total	129

For every item of the questionnaire, the scores from all the respondents of the same TPS were averaged. The averaged scores were compared amongst the 3 TPSs, the higher the mean score, the better would be the TPS for that item. For each aspect of the TPS, an overall mean score was obtained by taking the mean of the averaged scores of all the items under that aspect. The overall mean scores were also compared amongst the 3 TPSs. Although each respondent might have different interpretation of the scoring grades in the questionnaire, the difference would not cause bias to the overall result. It was because the recruitment of the

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respondents was a randomised process in which variations of the scoring standard already existed among respondents of the same TPS group and this would cancel out the possible scoring standard variations between the 3 different TPS groups.

Dosimetric accuracy

The beam data of a 6 MV linear accelerator from one of the participating hospitals was transferred to the 3 TPSs along with the necessary beam fitting and validation processes. A commercial solid water (RMI) phantom system was used for dose measurement. The phantom consisted of homogeneous unit density slabs of different thickness and slabs of different density values to simulate bones and lung tissues (Table 2). Six set-up conditions were designed in which rectangular solid phantom slabs of different thickness and density values were compiled to form a block of dimensions 30 (width) × 30 (length) × 19 (height) cm^3 (Table 3, Fig 1a–f). The six phantom set-up conditions consisted of different combinations including the homogeneous unit density medium, heterogeneous media mimicking bone and lung tissues, which were used to simulate the common radiation treatment conditions. A reference point was assigned to be the point of dose measurement in each set-up condition. The six phantoms were irradiated under 18 different exposure conditions; each was given a dose of 2 Gy at the point of measurement. For the unit density phantom (set-up I and VI), radiation beams with wedge, oblique incidence, median block

Table 2. Details of the phantoms used for dose measurement

Material	Bone equivalent	Lung tissue equivalent
RMI model no.	450–330	455–310
Nominal electron density relative to water	1.707	0.292
Nominal physical density (g/cm^3)	1.840	0.300

Table 3. Descriptions of the phantom set-up and irradiating conditions

	Phantom set-up details	Point of dose measurement*	Field no.	Field details
(I)	19 cm thick unit density phantom	5 cm below surface	1	10 × 10 cm^2 open field
			2	5 × 5 cm^2 open field
			3	10 × 10 cm^2 45° wedged field
			4	10 × 10 cm^2 open field with 45° oblique incidence
			5	20 × 20 cm^2 irregular field The field has a shape of arrow
(II)	6 cm unit density phantom on top of 1.5 cm bone density phantom followed by 11.5 cm unit density phantom	2 cm below bone density phantom	1	10 × 10 cm^2 open field
			2	5 × 5 cm^2 open field
			3	4 × 4 cm^2 open field
(III)	Same as II	1 cm above the bone density phantom	1	10 × 10 cm^2 open field
			2	5 × 5 cm^2 open field
			3	4 × 4 cm^2 open field
(IV)	2 cm unit density phantom on top of 3 cm lung density phantom followed by 14 cm unit density phantom	2 cm below the lung density phantom	1	10 × 10 cm^2 open field
			2	5 × 5 cm^2 open field
			3	4 × 4 cm^2 open field
(V)	6 cm unit density phantom on top of 3 cm lung density phantom followed by 10 cm unit density phantom	1 cm above the lung density phantom	1	10 × 10 cm^2 open field
			2	5 × 5 cm^2 open field
			3	4 × 4 cm^2 open field
(VI)	19 cm thick unit density phantom	5 cm below surface		10 × 10 cm^2 open field with 2 cm median lead block

*Chamber was placed at the central field axis in all cases.

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and irregular shape beam block were used. For the other 4 phantom configurations with heterogeneous media, open fields of $4 \times 4\,cm^2$, $5 \times 5\,cm^2$ and $10 \times 10\,cm^2$ were applied.

The 18 irradiating conditions were also constructed by the TPS using exactly the same phantom dimensions and densities as stated in Table 3. The treatment fields were constructed according to the specified exposure conditions. The dose to the dose measurement reference point was calculated for each phantom set-up and exposure condition. The most accurate dose algorithm of the TPS was used for each calculation.

Actual dose measurements were performed using the 6MV linear accelerator. The machine was first calibrated prior to each dose measurement. The doses to the points of interest were measured with a BICRON 2571 ionisation chamber placed at the reference point. The irradiating conditions were set-up as stated in Table 3. The point dose measurement for each set-up was repeated three times and the average value was taken.

The values obtained from the actual dose measurement were taken as the standard and were used to compare with those calculated from the 3 TPS. The percentage dose deviation was calculated for each measurement, which was the difference between the measured and calculated values divided by the measured value. The TPS that presented with the smallest percentage dose deviation was regarded as the most accurate for that measuring condition.

RESULTS

User-friendliness

There were 11 completed questionnaires received for each TPS in the study. They included radiographers and physicists. Overall, about 75% of the average scores for the 3 TPS was 3.5 or above (out of 5). Users were most satisfied with the construction of treatment field with the average scores of above 4.0, whereas scores received for the generation of digitally reconstructed radiograph (DRR) was relatively low, around 3.0.

Among the 3 systems, the number of aspects that scored 3.5 or above was similar. It was 10 for the Focus system, and 9 for the CadPlan and Pinnacle systems (Table 4). If 'outstanding performance' was defined as the one whose average score was higher than the other two systems by 0.2 points, the CadPlan was outstanding in the plan output which was the plotting and network transfer of treatment plans to other workstations. Whereas the Focus was outstanding in the construction of treatment aids, and the Pinnacle in the outlining, modification of field parameters, control of graphics and normalization of dose. In terms of individual items, the 3 systems presented with

Table 4. *Scores of the various aspects of user-friendliness by the three TPS*

Aspects of TPS	Average scores		
	CadPlan	Pinnacle	Focus
CT/MRI images transfer (4)	3.7	3.8	3.7
Outlining and structure delineation (13)	3.5	4.0	3.5
Construction of treatment field (14)	4.0	4.3	4.2
Construction of treatment aids (8)	3.4	3.5	3.8
Modification of field parameters (21)	3.8	4.1	3.7
Evaluation of treatment plans (13)	3.7	3.9	3.7
Control of graphics (21)	3.1	3.7	3.5
Normalization of dose (3)	3.6	4.3	3.6
Dose calculation (4)	3.5	3.5	3.5
MU calculation (3)	3.3	3.4	3.4
DRR generation (4)	2.8	3.2	3.3
Plan output (7)	3.8	3.4	3.5
System administration (14)	3.5	3.4	3.3

( ) indicates the number of evaluation items under the specified aspect.

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Table 5. List of outstanding items about the user-friendliness of the three TPSs

Outstanding items		
CadPlan	**Pinnacle**	**Focus**
Control of plan plot size	Outlining is simple and accurate	Define materials and thickness of customized blocks
Transfer plans to other workstations	Copy structures between CT slices	Define margin for conformal blocks
Free from software bugs	Move outlined structures	Add bolus
	Add wedge	Add compensator
	Delete or disable a beam	Generate dose profile along any selected plane
	Generate DVH	Manipulate orientation icon
	Select window format	Switch on/off specific dose volume
	Select and change colour of structures	
	Switch on/off a beam	
	Adjust window/level of CT	
	Modify normalization point and dose	
	Define calculation volume	

different strengths, with the Pinnacle doing relatively well in items related to graphics and field modification tools (Table 5).

Dosimetric accuracy

In general, the 3 TPSs produced fairly accurate dose calculation in the irradiation conditions under evaluation. The percentage deviations between the measured and calculated values were all within ±3%, except for the field with a 2 cm central lead block. The performance of the TPS in different phantom set-up conditions were different and no one system gave superior results in all measuring conditions.

For the set-up using unit density phantom (Set-up I), all the 3 TPSs showed percentage dose deviations of less than 2%. The Pinnacle system showed relatively smaller deviations, whereas the CadPlan system showed slightly greater deviation for the fields with wedge and oblique incidence (Fig. 2). The Focus system was intermediate between the two.

In Set-up II where the dose measurement point was 2 cm below a 1.5 cm layer bone, similar results as Set-up I were obtained. The Pinnacle produced relatively small deviations (±1.1%) for all the three field sizes. The CadPlan showed larger deviations (3%) and the Focus was the intermediate (Fig. 3). The results in Set-up III, in which the dose measurement point was 1 cm above a 1.5 cm layer bone, were similar among the three systems. All the percentage deviations were within 1.2% with CadPlan producing relatively better result (Fig. 4).

In Set-up IV where the dose measurement point was 2 cm below a 3 cm layer lung, the Focus and Pinnacle systems gave similarly good results with percentage deviations below 0.5%. The performance of the CadPlan was slightly behind with the dose deviations being within ±3% (Fig. 5). The results in Set-up V, in which the dose measurement point was 1 cm above a 3 cm layer lung, were fairly different from that in Set-up IV. The CadPlan and Focus systems gave similar good dose agreements with the percentage deviations within ±0.5%, whereas the Pinnacle showed a relatively large percentage deviation of 1.3% (Fig. 6).

In Set-up VI, in which a $10 \times 10\,cm^2$ beam with a 2 cm wide central lead block incident on the unit density phantom, the Focus showed the smallest percentage dose deviation of 2.7% followed by Pinnacle and CadPlan, whose deviations were 4.8% and 5.1% respectively (Fig. 7).

DISCUSSION AND CONCLUSION

Studies on the comparison of different TPS for 3DCRT had been documented.[7,8] They were conducted using either more general or physics oriented approach. Studies that involve objective evaluation from the users' perspective were very limited. Though the method used in this study

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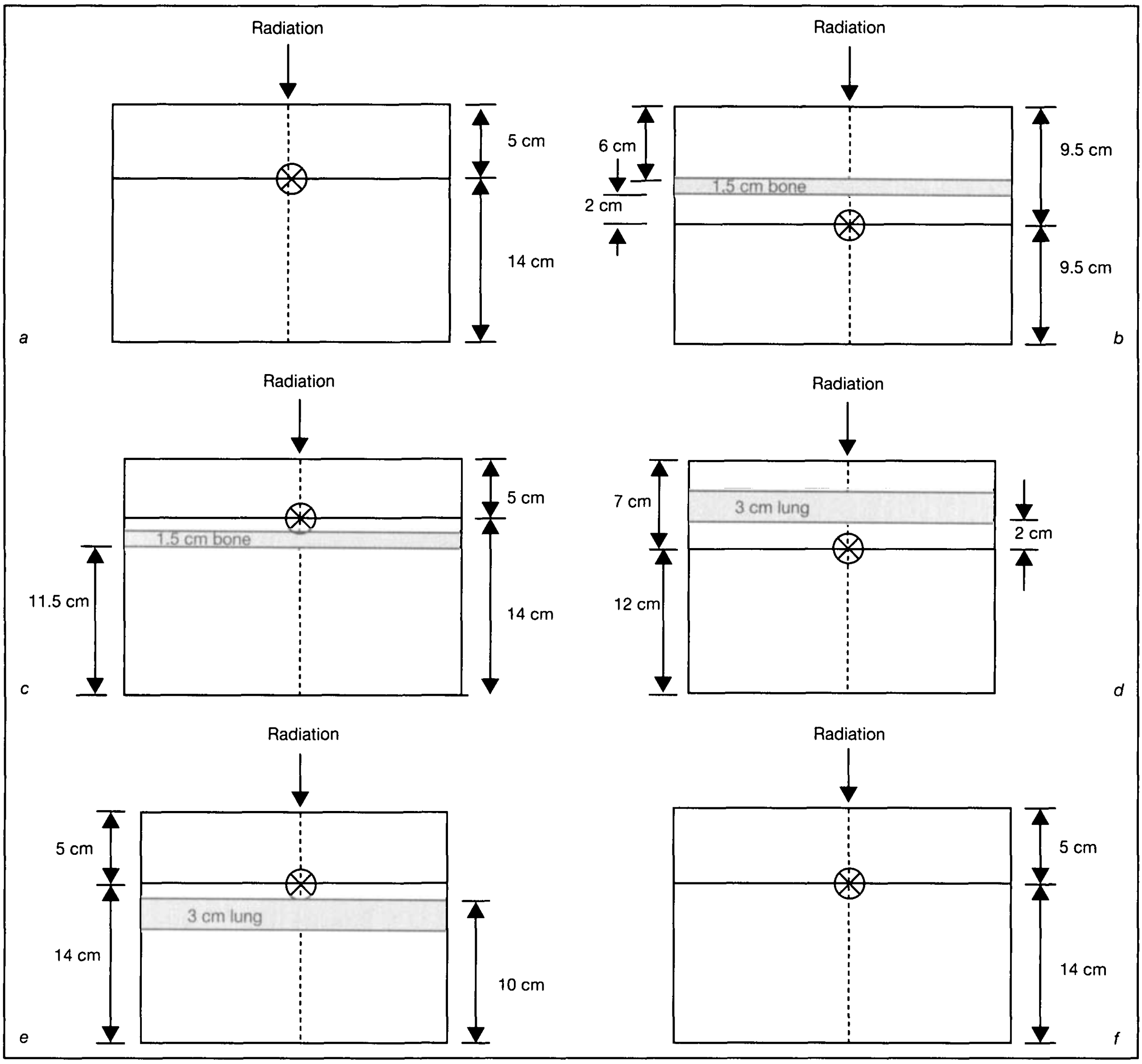

Figure 1a–f. Diagrams showing the 6 phantom set up conditions (not in proportion): a = set up I; b = set up II; c = set up III; d = set up IV; e = set up V; f = set up VI

was relatively simple, the major concerns of TPS users, i.e. both user-friendliness and dosimetric accuracy of the systems were addressed. This study can be extended to other models of 3DCRT TPS in the market and conducted at different time intervals so as to obtain update information on the TPS performance.

In this study, it has been found that all the 3 TPSs in general demonstrated good and acceptable performance both in the aspects of user-friendliness and dosimetric accuracy. For the 3 TPSs, users were satisfied with the majority of the operating procedures, as was reflected by the relatively high scores of 3.5 or above in most of the items. In terms of user-friendliness, individual system had its own strengths and no one system was superior in every aspect. Taking into account all the performance aspects in the questionnaire and assuming all items carried equal weights, the Pinnacle appeared to be relatively more user-friendly, with better performance in the graphics and field parameters manipulation.

In terms of dosimetric accuracy, the measured and calculated data for the 3 TPS showed fairly

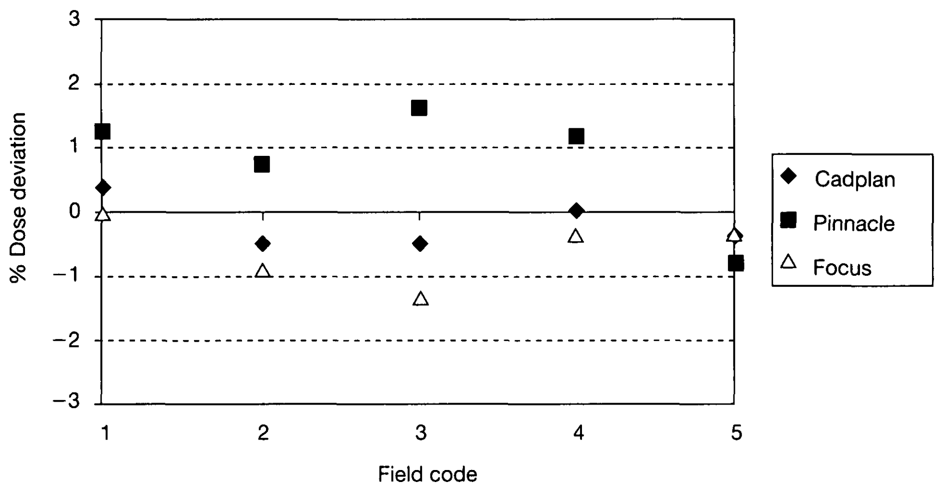

Figure 2. Comparison of percentage dose deviation by the three TPS under phantom set up I.

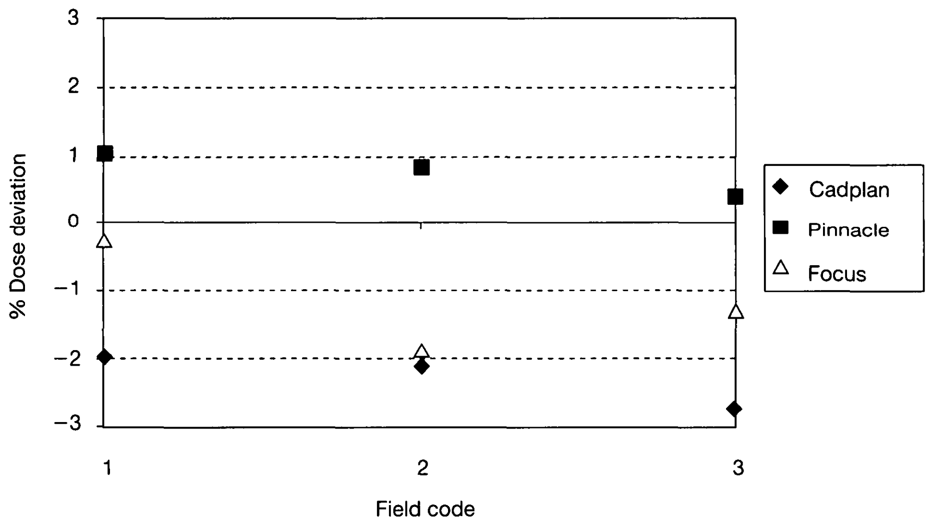

Figure 3. Comparison of percentage dose deviation by the three TPS under phantom set up II.

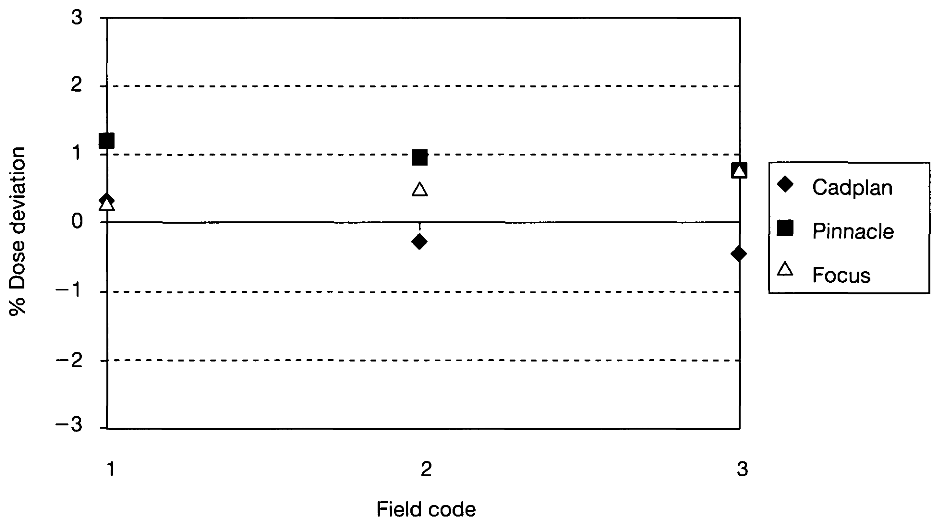

Figure 4. Comparison of percentage dose deviation by the three TPS under phantom set up III.

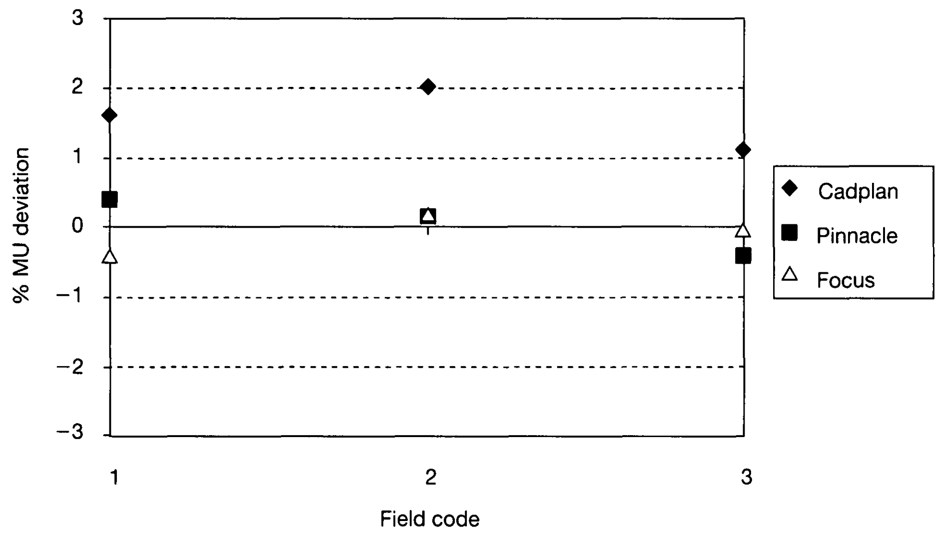

Figure 5. Comparison of percentage dose deviation by the three TPS under phantom set up IV.

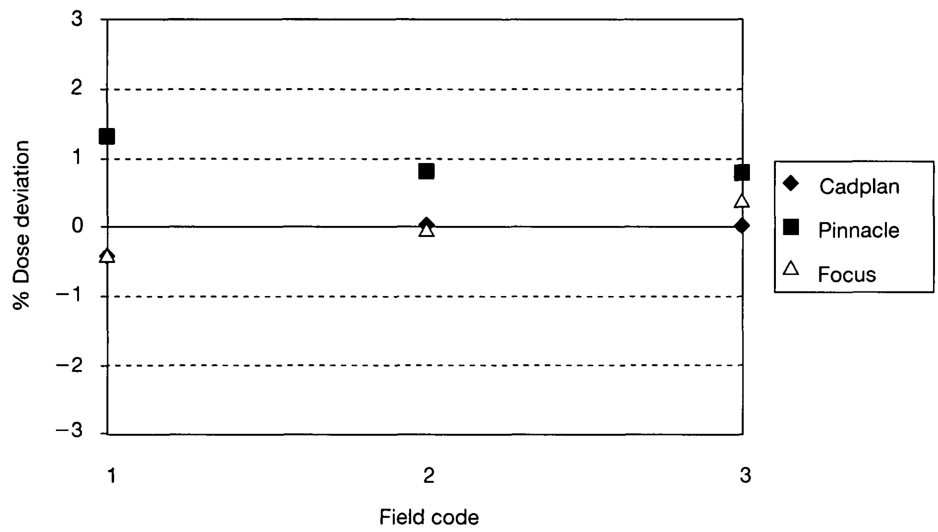

Figure 6. Comparison of percentage dose deviation by the three TPS under phantom set up V.

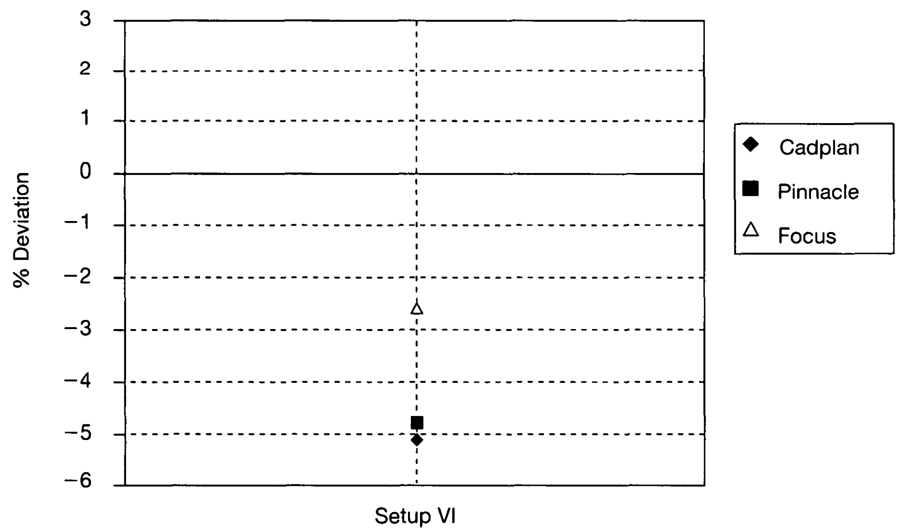

Figure 7. Comparison of percentage dose deviation by the three TPS under phantom set up VI.

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good agreement. It reflects the fact that after over 15 years of development in the dosimetry algorithms of the 3DCRT planning systems by different vendors, most of the systems are now mature and are able to give good prediction on the dose received by the real patient in treatment. With regards to the 3 TPS in this study, the Pinnacle and Focus system both used superposition algorithm whereas the CadPlan employed the pencil beam algorithm. Such algorithms are much more accurate than the conventional 2-D correction based algorithms used in the past. By theory, the superposition algorithm is more sophisticated than the pencil beam algorithm. However, except for the field with median block, in which the Focus system presented with the best result, the differences between the three planning systems in terms of accuracy were not obvious. The percentage dose deviations fell within ±3%. In general, the CadPlan presented slightly more accurate results under the unit density phantom conditions (Set-up I), whereas the Focus gave relatively more accurate calculation in the other irradiating conditions with heterogeneous media.

In conclusion, with regards to the user-friendliness and dosimetric accuracy, each of the three treatment planning systems evaluated in this studies has its own strengths and weaknesses and no one system gives better performance in all aspects of the test.

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