Image Display for Collision Avoidance of Radiation Therapy: Treatment Planning

By Max M. Chao, Liang S. Chao, Yu J. Chen, Chuen M. Hsieh, Shueh C. Liou, Yuh L. Lee, and Sang H. Yen

Patient treatment in a medical linear accelerator is characterized by many angular and translational movements of the gantry and couch. The direction and orientation of each treatment beam is specified by a set of gantry, turntable, and collimator angles. It is possible that some selected treatment field configurations will result in gantry/couch or gantry/patient collisions that remain undetected during the treatment planning process. In this work, a digital camera has been used to record all the workable gantry/patient set-up images, and a Windows programming language is used to edit and display these images on a personal computer for the treatment planner to screen the treatment plans. These graphical displays enable the planner to be aware of any potential collision hazards by an actual visualization of each selected gantry/turntable or gantry/patient angle configuration.

Copyright © 2001 by W.B. Saunders Company

KEY WORDS: image display, collision avoidance, treatment planning.

MODERN SOPHISTICATED medical linear accelerators and treatment planning systems allow optimal implementations of the 3-dimensional (3D) treatment planning systems.^{1,2} A linear accelerator is characterized by many angular and translational movements. The direction and orientation of each beam is specified by a set of gantry, turntable, and collimator angles.^{3,4} With the advancement of 3D treatment planning systems, there is an increased use of nonaxial and oblique treatment fields that require many couch rotations.⁵ The virtual visualization of the direction and orientation of a beam specified by a set of machine angles sometimes can be very difficult for some treatment set-ups, particularly for noncopla-

nar plans.^{6,7} It is possible that some selected field configurations will result in gantry/couch or gantry/patient collisions that have remained undetected during the treatment planning process. There is considerable literature associated with collision avoidance.⁸⁻¹³ A variety of approaches have been used to prevent these problems.¹⁴⁻¹⁹ In this work, a digital camera has been used to record all the permissible gantry/patient set-up images, and a Windows programming language is used to edit and display these images on a personal computer for the treatment planner to screen all the treatment plans. These graphical images enable the planner to visualize the relationship between the gantry and the patient or couch at all times during the development of a treatment plan. The purpose of this collision avoidance strategy is to test the safety of each new patient treatment plan on the treatment machine and to eliminate any unfeasible treatment plan. All of above assume that the patient does not move during the treatment because good patient immobilization is essential to ensure the successful implementation of a treatment plan. Many options can be used. The more independent systems applied, the lower the risk of actual collision.

MATERIALS AND METHODS

The coordinate system that has been adopted to define treatment machine axes, and gantry and turntable angles is the International Electrotechnical Commission coordinate system.³ The gantry angle θ is zero for the gantry in the upright position and increases with the clockwise rotation. The turntable angle ϕ is zero as the couch parallels the gantry axis and increases with a counter-clockwise rotation as looking down on the couch. Head and neck cancer patients being treated with a Siemens Mevatron KD2 linear accelerator treatment machine (Siemens Medical Systems Inc, Concord, CA) equipped with a retractable beam stopper were chosen to test the conditions for a collision between the gantry and the couch or the patient. To evaluate whether a gantry/couch or gantry/patient collision would occur, we set the Alderson Rando Phantom (Alderson Research Laboratories Inc, Stamford, CT.) on the couch to model the patient. The turntable angle ϕ was fixed at 0° , and the gantry angle rotated θ from 0° to 360° at 10° intervals. A Ricoh RDC-2 Digital camera (Ricoh Corporation, West Caldwell, NJ) was used to record all gantry/couch or gantry/patient images that included the patient safety margin. Then, the turntable angle ϕ was rotated at 10° intervals with the gantry angle θ rotated from 0° to 360° at each 10° turntable rotation interval. Given the coordinate system definition, the allowed turntable angles are

From the Cancer Center and Cancer Research Group, Veterans General Hospital-Taipei, Taipei, Taiwan, Republic of China.

Supported by the National Science Council of Republic of China, Grant No. NSC 89-2320-B-166-001-M08.

Address reprint requests to Max M. Chao, PhD, Associate Professor, Department of Radiological Technology, Chungtai Institute of Health Sciences and Technology, 11 Pu Tzu Lane, Taichung, Taiwan 40605, Republic of China.

*Copyright © 2001 by W.B. Saunders Company
0897-1889/01/1404-0003\$35.00/0*

limited to 0° to 90° and 270° to 360°. The collision status for the Siemens Mevatron KD2 treatment machine with turntable angle ϕ from 0° to 90° and from 270° to 360° and gantry angle θ from 0° to 360° all were recorded with our RDC-2 Digital camera.

The RDC-2 digital camera has a 768 × 576 pixel matrix with 200 dpi resolution and 1,297 Kbytes unprocessed image file size. Photoshop 5.0 imaging software (Adobe Systems Incorporated, San Jose, CA) was used for image editing and transferring image files to the IBM personal computer hard disk to be stored as bmp (bit map) files. The computer used was an IBM personal computer 300GL with 500MHz Pentium III central processing unit and 128MB RAM (IBM Corporation, White Plains, NY) with the Windows98 operating system (Microsoft Corporation, Redmond, WA). The graphical interface used the Borland C++ builder 4 (BCB4) programming language (Inprise Corporation, Scotts Valley, CA) to perform the Windows graphics display, which included user interaction dialog boxes.²⁰ This system displayed the actual photo images of the specified turntable angles and gantry angles and automatically checked whether the gantry/turntable or gantry/patient angle configuration was allowed. The graphical display of photo images with dialog boxes can be transmitted as a file transfer protocol (ftp) file to a Codonics NP-1600M medical color printer (Codonics Inc, Middleburg Heights, OH) on the Local Area Network (LAN) to print on a photo-quality hardcopy output result for documentation.

RESULTS

To test the results of the collision detection and avoidance system for the Siemens Mevatron KD2 treatment machine for head and neck cancer patients, a data set of a full 360° rotation of the gantry, in 5° intervals, at turntable angle incre-

Table 1. The Permissible Gantry Angle θ Status for the Siemens Mevatron KD2 Treatment Machine of Head and Neck Cancer Patient With the Beam Stopper in Place

Couch Angle (degrees)	Gantry Range (degrees)	Couch Angle (degrees)	Gantry Range (degrees)
0	0-360	360	0-360
10	0-360	350	0-360
20	0-360	340	0-360
30	0-15	330	0-90
	140-180		180-220
	360-270		360-345
40	145-180	320	0-60
	360-300		180-215
50	145-180	310	0-40
	360-320		180-215
60	145-180	300	0-40
	360-320		180-215
70	145-180	290	0-40
	360-320		180-215
80	145-180	280	0-40
	360-320		180-215
90	145-180	270	0-40
	360-320		180-215

Table 2. The Permissible Gantry Angle θ Status for the Siemens Mevatron KD2 Treatment Machine of Head and Neck Cancer Patient Without the Beam Stopper in Use

Couch Angle (degrees)	Gantry Range (degrees)	Couch Angle (degrees)	Gantry Range (degrees)
0	0-45	360	0-45
	360-270		360-270
10	0-45	350	0-45
	360-270		360-270
20	0-45	340	0-45
	360-270		360-270
30	0-45	330	0-45
	360-270		360-270
40	0-45	320	0-45
	360-300		360-270
50	0-45	310	0-40
	360-320		360-270
60	0-45	300	0-40
	360-320		360-270
70	0-45	290	0-40
	360-320		360-270
80	0-45	280	0-40
	360-320		360-270
90	0-45	270	0-40
	360-320		360-270

NOTE. The gantry angle θ has additional consideration for radiation safety if the treatment beam passes through the left hand side wall to the next treatment room or the ceiling of this basement treatment room.

ments in 10° intervals between 0° to 90° and 270° to 360°, was generated. Table 1 lists the permissible gantry angle θ status for the gantry with the beam stopper in use. Table 2 is for the gantry without the beam stopper. Because of the absence of the beam stopper in Table 2, the gantry angle θ has an additional radiation safety constraint (in our facility layout) to prevent the treatment beam from passing through the left hand side wall to the next treatment room or the ceiling of this basement treatment room. Table 3 includes an example of the collision status for the gantry angles from 0° to 360° in 10° intervals with the turntable angles of 30° and 270° with the beam stopper in place. Table 4 has these same parameters but without the beam stopper. The recommend angle in columns 3 and 5 of Tables 3 and 4 are the nearest allowed gantry angle either above or below the turntable. In Table 4, radiation safety considerations also were taken into account as discussed above with additional constraints on the gantry angles θ .

Figure 1 displays an image of near collision between the gantry and a patient in a head and neck fixation mold on the Siemens Mevatron KD2 treat-

Table 3. The Collision Status for the Gantry Angles θ From 0° to 350° in 10° Intervals With the Turntable Angles ϕ of 30° and 270° of the Beam Stopper in Use

Gantry Angle (degrees)	Couch 30°		Couch 270°	
	Collision Status	Recommend Angle (degrees)*	Collision Status	Recommend Angle (degrees)*
0	No	—	No	—
10	No	—	No	—
20	Yes	15	No	—
30	Yes	15	No	—
40	Yes	15	No	—
50	Yes	15	Yes	40
60	Yes	15	Yes	40
70	Yes	15	Yes	40
80	Yes	140	Yes	40
90	Yes	140	Yes	40
100	Yes	140	Yes	40
110	Yes	140	Yes	40
120	Yes	140	Yes	180
130	Yes	140	Yes	180
140	No	—	Yes	180
150	No	—	Yes	180
160	No	—	Yes	180
170	No	—	Yes	180
180	No	—	No	—
190	Yes	180	No	—
200	Yes	180	No	—
210	Yes	180	No	—
220	Yes	180	Yes	215
230	Yes	270	Yes	215
240	Yes	270	Yes	215
250	Yes	270	Yes	215
260	Yes	270	Yes	215
270	No	—	Yes	215
280	No	—	Yes	215
290	No	—	Yes	0
300	No	—	Yes	0
310	No	—	Yes	0
320	No	—	Yes	0
330	No	—	Yes	0
340	No	—	Yes	0
350	No	—	Yes	0

*Nearest allowed gantry angle.

ment system. Figure 2 shows an image of near collision at gantry and couch pedestal for this Siemens Mevatron KD2 unit. Examples of the BCB4 algorithm graphical display are shown in Figs 3 and 4. Figure 3 illustrates an executed result in the Siemens Mevatron KD2 treatment machine for head and neck cancer with 320° gantry angle and at 30° couch angle with the beam stopper in position, and Fig 4 is for 270° gantry angle and 270° couch angle without the beam stopper in place.

DISCUSSION

For a linear accelerator, the direction and orientation of a beam is defined by a set of gantry, turntable, and collimator angles. Sometimes it is very difficult for the planner to visualize the set-up of a treatment beam from the specified gantry and couch angles for each beam. During treatment

Table 4. The Collision Status for the Gantry Angles θ From 0° to 350° in 10° Intervals With the Turntable Angles ϕ of 30° and 270° Without the Beam Stopper in Place [Columns 3 and 5 are the Nearest Allowed Gantry Angle]

Gantry Angle (degrees)	Couch 30°		Couch 270°	
	Collision Status	Recommend Angle (degrees)*	Collision Status	Recommend Angle (degrees)*
0	No	—	No	—
10	No	—	No	—
20	No	—	No	—
30	No	—	No	—
40	No	—	No	—
50	No	45	Yes	40
60	No	45	Yes	40
70	No	45	Yes	40
80	No	45	Yes	40
90	No	45	Yes	40
100	No	45	Yes	40
110	No	45	Yes	40
120	No	45	Yes	40
130	No	45	Yes	40
140	No	45	Yes	40
150	No	45	Yes	40
160	No	45	Yes	40
170	No	45	Yes	40
180	No	270	No	270
190	Yes	270	No	270
200	Yes	270	No	270
210	Yes	270	No	270
220	Yes	270	No	270
230	Yes	270	No	270
240	Yes	270	No	270
250	Yes	270	No	270
260	Yes	270	No	270
270	No	—	No	—
280	No	—	No	—
290	No	—	No	—
300	No	—	No	—
310	No	—	No	—
320	No	—	No	—
330	No	—	No	—
340	No	—	No	—
350	No	—	No	—

NOTE. The gantry angle θ has additional consideration for radiation safety if the treatment beam passes through the left hand side wall to the next treatment room or the ceiling of this basement treatment room.

*Nearest allowed gantry angle.

Fig 1. A near-collision image between the gantry and a patient in a head and neck fixation mold on the Siemens Mevatron KD2 treatment machine.

planning, it can be difficult to check whether a particular plan is workable, that is, it avoids blocking treatment beams with parts of the patient couch and avoids collisions between the treatment machine head and the couch or patient. Many ap-

Fig 2. A near-collision image between the gantry and bottom of the couch for the Siemens Mevatron KD2 unit.

proaches have been used to prevent these problems at the time of plan verification or at the patient's first-day treatment, such as tables or graphs of prohibited angles, or the use of graphical simulator.^{5,8,9} There also is the possibility of using developed devices and models to check the machine angles or visualize the beam orientation in a treatment plane.⁷ These approaches have different strengths and weaknesses. Tables are simple, quick, and inexpensive to produce and use but usually use simplifying assumptions during their production. Machine angle or the beam orientation devices and models again usually only provide simplified solutions to the problems.¹⁵

Software can never be 100% error free, and no collision avoidance system should rely on software checks alone. The planner should feel confident that all the fields arranged can be treated, and no machine collisions are possible. To assist the planner in the treatment design, we have developed a graphical interface by using the BCB4 programming language to display an actual photo image of

Figure 3

Figure 4

Fig 3. (Top image). An executed result in Siemens Mevatron KD2 treatment machine for head and neck cancer of 320° gantry angle and 30° couch angle with the beam stopper in position.

Fig 4. (Bottom image). An executed result in Siemens Mevatron KD2 treatment machine for head and neck cancer of 270° gantry angle and 270° couch angle without the beam stopper in used result.

the gantry/patient set-ups in the treatment room for the selected treatment fields. This enables the accurate visualization of each treatment field configuration within a treatment planning software window and allows the planner to be aware of, and avoid, any potential collision hazards. In this window, a planner can explore new treatment fields and continuously visualize the relation of the gantry and the patient. This graphical collision avoidance method also enables the planner to obtain

immediate feedback of the feasibility of each additional treatment field during the treatment planning process.

The actual photo of gantry/patient set-up images, which were taken by a digital camera, have been transferred to our treatment planning room's computers. This method enables the planner to explore unconventional noncoplanar treatment fields and test their feasibility immediately. Although, in this study, the collision analysis is applied to the Siemens Mevatron KD2 linear accelerator, the approach can be adapted easily for any other treatment machines or treatment sites.

ACKNOWLEDGMENT

The authors thank the following people for their helpful collaborations: Kuan W. Hwang, Ye S. Wu, Che Z. Shao, Li W. Lin, and Ton S. Hsieh.

REFERENCES

1. Mohan R, Barest G, Brewster LJ, et al: A comprehensive three-dimensional radiation treatment planning system. *Int J Radiat Oncol Biol Phys* 15:481-495, 1988
2. Rosen II, Lane RG: Treatment plan optimization for radiation therapy, in *Proceedings of the use of computers in radiation therapy*. Amsterdam, Elsevier, 1987, pp 357-360
3. International Electrotechnical Commission: Radiotherapy equipment—Coordinates, movements and scales. IEC 61217:1-137, 1996
4. Bortfeld T, Schlegel W: Optimization of beam orientations in radiation therapy: Some theoretical considerations. *Phys Med Biol* 38:291-304, 1993
5. Kessler ML, McShan DL, Fraass BA: A computer-controlled conformal radiotherapy system: Graphical simulation and monitoring of treatment delivery. *Int J Radiat Oncol Biol Phys* 33:1173-1180, 1995
6. Seaby AW, Thomas M: Two-dimensional kinetic models for radiotherapy planning quality assurance. *Br J Radiol* 72:193-195, 1999
7. Seaby AW, Thomas M: A model simulator for radiotherapy treatment planning and checking. *Br J Radiol* 72:293-295, 1999
8. Humm JL, Pizzuto D, Fleischman E, et al: Collision detection and avoidance during treatment planning. *Int J Radiat Oncol Biol Phys* 33:1101-1108, 1995
9. Humm JL: Collision avoidance in computer optimized treatment planning. *Med Phys* 21:1053-1064, 1994
10. Moorthy SM: A method of beam-couch intersection detection. *Med Phys* 26:229-235, 1999
11. Bayouth J, Muthuswamy M, Kalend A, et al: Computer controlled conformal therapy-analytical and computer simulation of collision avoidance and treatment delivery. *Int J Radiat Oncol Biol Phys* 32:188, 1995
12. Kyriakopoulos KJ, Saridis GN: An integrated collision prediction avoidance for mobile robots in nonstationary environments. *Automatica* 29:309-322, 1993
13. Yorke ED: The geometry of avoiding beam intersections and blocking tray collisions. *Med Phys* 16:288-291, 1989
14. Everett HR: Survey of collision avoidance and ranging sensors for mobile robots. *Robot Auton Systems* 5:5-67, 1989
15. Beange I, Nisbet A: A collision prevention software tool for complex three-dimensional isocentric set-ups. *Br J Radiol* 73:537-541, 2000
16. Leou JJ, Chang YL, Wu JS: Robot operation monitoring for collision avoidance by image sequence analysis. *Pattern Recogn* 25:855-867, 1992
17. Suh SH, Bishop AB: Collision-avoidance trajectory planning using tube concept: Analysis and simulation. *J Robot Syst* 5:497-525, 1988
18. Sherouse GW, Chaney EL: The portable virtual simulator. *Int J Radiat Biol Phys* 21:475-482, 1991
19. Appleby H: The pocket linac—A hand-held device for finding IEC collimator angles and independent jaw settings. *Radiation Oncol* 42:311-313, 1997
20. Comer DE, Stevens DL: *Internetworking with TCP/IP, Vol 3, Client-server programming and applications*. Englewood Cliffs, NJ, Prentice Hall, 1993