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● *Physics Contribution*

COMPARISON OF TWO HEAD AND NECK IMMOBILIZATION SYSTEMS

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Purpose: Accurate and reproducible patient positioning is fundamental to the success of fractionated radiotherapy. Concurrent with the introduction of three-dimensional treatment planning capabilities at our institution, a head and neck immobilization system consisting of a standard foam rubber head support and three casting strips was replaced by a customized mask-based device. This study was performed to analyze the impact of the customized immobilization system on the reproducibility of patient setup during irradiation of head and neck and brain tumors.

Methods and Materials: Patients treated from 1989–1991 were immobilized with the strip system while those treated from 1991–1995 were immobilized with the mask. All treatment fields were simulated and were treated on a 4 MV (where the strip, but not the mask, system was fixed to the treatment couch) or ≥ 6 MV (where both the strip and the mask systems were fixed to the couch) accelerator. Port films were taken on the initial treatment day, routinely during treatment, and following shifts (requested). The number, magnitude, and direction of any isocenter shifts were retrospectively reviewed. A two-tailed *chi* square test was used to compare the differences in requested shifts in the strip and mask groups.

Results: The study population consisted of 69 brain tumor (35 strip, 34 mask) and 71 head and neck (37 strip, 34 mask) patients. A total of 1575 port films representing 1070 isocenter placements were analyzed. No differences between the immobilization systems was seen on the 4-MV accelerator (where the mask system was not fixed to the couch). On the ≥ 6-MV units, the frequency of shifts was 16.1% versus 6.2% ($p = 0.002$) with the strips and mask, respectively. Almost all of the benefit was seen in the routine films, where the corresponding rates were 13.2% and 4.1% ($p = 0.007$). For the mask system, the rate of requested shifts on routine films was 4.1% (8/197) for the ≥ 6-MV units and 14.5% (24/166) for the 4-MV unit ($p = 0.001$).

Conclusion: Using the frequency of physician-requested isocenter shifts as an indicator of the accuracy of patient repositioning, the newer mask system appears to be an improvement over the previously used strip system, provided that the immobilization device is secured to the treatment couch. Increased accuracy of daily setup provides an opportunity to improve the therapeutic ratio both by increased likelihood of tumor control and decreased risk of normal tissue complications. © 1997 Elsevier Science Inc.

Brain irradiation, Head and neck irradiation, Immobilization, Devices, Accuracy, Setup, Mask, Cradle, Thermoplastics.

INTRODUCTION

The ability to accurately and reproducibly position the patient during a course of radiation is fundamental to fractionated radiation therapy. This is particularly true when the target is located adjacent to radiosensitive structures, or when the margins surrounding the target are small. This situation is frequently encountered when the head-and-neck area is irradiated. The risks of inadvertently irradiating non-target tissues must be minimized and every effort should be made to accurately irradiate the target. Various techniques to immobilize the head-and-neck region have been described (1, 3–9, 11, 14, 15).

Concurrent with the implementation of three-dimensional treatment planning (3D TP) at Duke University Medical Center, we introduced a customized head-and-neck immobilization system (3). In this study, we retrospectively assessed the impact of this immobilization system on the reproducibility of patient setup during radiotherapy for brain and head-and-neck tumors.

METHODS AND MATERIALS

In 1991, 3D TP was phased into routine clinical use at Duke University Medical Center. With this, the previously

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used standard head support was replaced with a new, customized head-and-neck immobilization system (3). We retrospectively investigated the effectiveness of the two immobilization systems by comparing the number of isocenter shifts requested by the monitoring radiation oncologist upon port film review.

Immobilization devices

Old system (strips). This device consisted of a standard foam rubber head support resting on a flat plastic base plate which in turn rests on the treatment couch. Three casting strips[1] placed across the face were fastened to the base plate (Fig. 1, left). One casting strip, placed under the chin, was fastened to a vertical metal bar at the cephalad portion of the base plate. A second casting strip, cupped around the chin, was fastened on both sides of the cephalad portion of the base plate. The third casting strip, placed across the forehead, was fastened on both sides of the caudal portion of the base plate near the patient's shoulders. The three strips crossed and adhered to each other on both sides of the patient's head. Set-up marks were made on the device when possible.

The lateral (outer) aspect of the base plate used with the strips had a "lip" that protruded down over the side of the couch to keep the base plate centered on the couch and parallel along the long axis of the couch (Fig. 1).

New system (mask). This consists of a custom-made head support, molded to conform to the back and the sides of the patient's head, neck and upper shoulders (Fig. 1, right) (3). A thermoplastic sheet,[2] softened in hot water, is draped over the patient's face and is then fastened to a base plate on top of the treatment couch. The mask, which is molded to fit tightly, covers the face from the mid-forehead to below the chin. Whenever possible, setup marks are made on the mask. A "lip", similar to that described for the strip system, was present on the base plate used on the ≥ 6-MV unit but not on the 4-MV unit.

Patient population

Beginning in mid-1991, patients with brain and head-and-neck tumors who underwent 3D TP were immobilized using the new mask system. During the latter half of 1992, we also began to use this system for patients who did not undergo 3D TP. Port films of 69 patients with brain tumors (35 with strips and 34 with masks), and 71 patients with head-and-neck tumors (37 with strips and 34 with masks) were reviewed. The charts and film jackets of patients with head-and-neck and brain tumors were randomly extracted from available files among those treated between 1989 and 1991 (strips) and between 1991 and 1995 (mask).

Target localization and treatment simulation

All patients, with the exception of two, one (brain tumor) in a mask and one (head-and-neck tumor) in the strips, underwent treatment simulation with marking of the central axes and field perimeters on the immobilization device. In some brain tumor patients treated with unusual non-coplanar beams, the actual treatment fields could not be marked on the mask; therefore, only reference marks, including the treatment isocenter were made. Some pa-

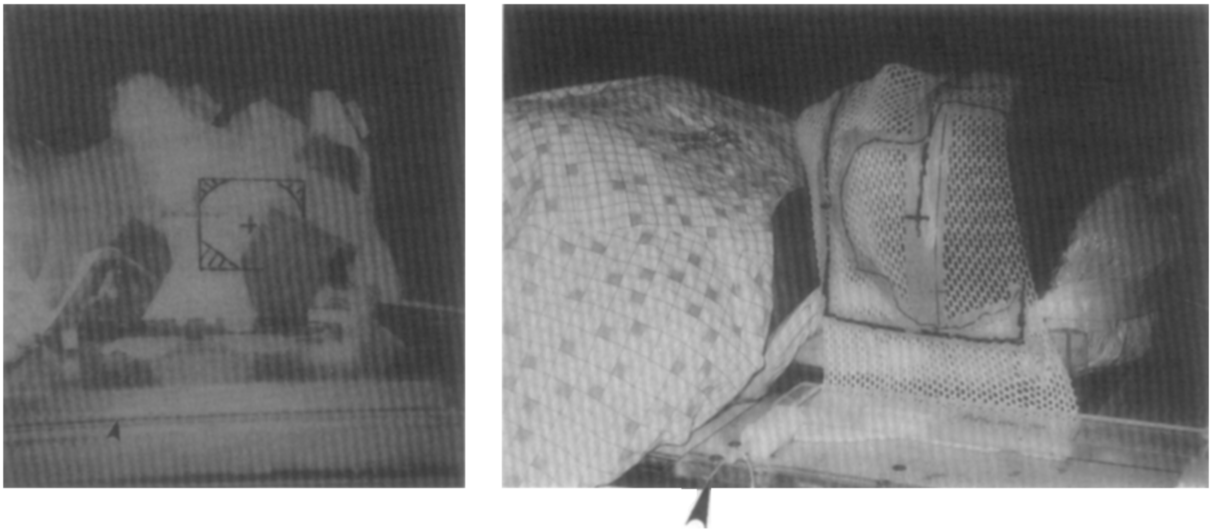

Fig. 1. Illustration of the strip (left) and the mask (right) immobilization devices. The strips and the mask are fastened to the base plate on each side of the head. The lateral aspect of the base plate has a "lip" (arrow) that protrudes down over the side of the couch (towards the floor) to keep the base plate centered on the couch and parallel to the long axis of the couch. This does not prevent motion of the base plate along the long axis of the couch.

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[1]Scotchcast™, 3M, St. Paul, MN.

[2]Aquaplast™, WFR Aquaplast Corp., Wyckoff, NJ.

tients had a second simulation procedure for reduced fields, at the physician's discretion.

Treatment

Field arrangements varied from opposed laterals to multiple non-coplanar beams, with the complex beam arrangements used only in the mask group. The majority of head-and-neck cancer patients were treated using shrinking opposed lateral fields. Reduced fields were usually accomplished by making a new set of blocks from the original simulation films. Twelve patients underwent a second simulation due to the need for a new central axis location or a new immobilization device. A variety of technical factors are outlined in Table 1. For patients treated using a ≥ 6-MV linear accelerator, the mask immobilization system was fastened to the treatment table while this was not done for patients treated using a 4-MV linear accelerator.

Port film review

An initial port film of each field was taken during the first treatment session to verify the field shape and location. Once approved, routine weekly port films were taken during treatment to verify continued accuracy. Patients treated twice per day (BID) had routine port films twice weekly. When opposed fields were used, a port film of only one of the fields was taken weekly, alternating between the two fields. If a misalignment was noted by the monitoring physician on either the initial or the routine films, an isocenter shift was requested and a requested port film was taken during the next treatment to verify the shift. During the evaluation of each port film, the physician generally noted the location of the isocenter (with respect to bony/soft tissue landmarks) relative to the simulator film. Port film graticules were used in some cases.

The typical practice in our department has been to request isocenter shifts in 5-mm increments, assuming that smaller misalignments may be difficult to detect and accurately correct. In patients who had 3-D TP with narrow tumor margins, shifts <5 mm were occasionally requested. All port films were reviewed every 1–2 weeks throughout treatment in quality assurance sessions attended by approximately 15–20 personnel, including physicians, dosimetrists, physicists, and technologists who commented on port film accuracy and assisted with interpretation of difficult films.

All port films were retrospectively reviewed by a single investigator (KH) to record the observations made by the monitoring physician. This review was not to determine whether the initial judgment in accuracy of the isocenter placement was proper. We recognize that the monitoring physician can make errors in reviewing the port films. These errors should have occurred throughout the study period and should be present in both groups; furthermore, the quality assurance techniques previously described hopefully minimized these errors. Although elaborate methods of analyzing port films have been described, it is not clear if they are more accurate (12). Given the very large number of port films that we wanted to review, that type of analysis was not practical. We believe that the endpoint used, physicians requested isocenter shifts, is a valid indicator of setup reproducibility. We recognize that errors in patient set up are complex and often reflect errors in both isocenter placement and rotations; however, it is extremely difficult to determine exactly why a port film does not accurately match the desired setup (12). Our practice, which we believe is common through the radiation oncology community, is to deal with discrepancies between simulation films and port films primarily by shifting the isocenter. Errors in rotations (unless very large) are usually much more difficult to detect. Given the difficulties in precisely analyzing the complex errors that lead to inadequate port films, we focused only on isocenter shifts. This review was retrospective, and neither the technologists treating the patients, nor the physicians reviewing the weekly port films were aware that these films would later be studied.

Initial, routine, and requested port films were considered separately. Errors in initial port films reflect both inaccuracies in patient set-up reproducibility, as well as systematic differences between the simulator and treatment room lasers, couch, etc., as described by other authors (10, 13). Because the goal was to assess reproducibility over the course of treatment, requested port films were considered separately because they were usually taken only one day following a prior film. In addition, it was thought that

Table 1. Technical factors by type of patient and immobilization

	Strips (number of patients)			Mask (number of patients)		
Technical factors	Head & neck	Brain	All	Head & neck	Brain	All
Beam Energy						
4 MV	25	20	45	28	4	32
≥6 MV	12	12	24	5	29	34
Both	0	3	3	1	1	2
Other						
Had second simulation	4	6	10	3	3	6
Twice-a-day treatment	19	2	21	15	6	21

Table 2. Technical accuracy by type of immobilization for all patients

	Strips		Mask		
	# isocenter shifts/ # times tested	Percent	# isocenter shifts/ # times tested	Percent	*p*-Value
INITIAL PORT FILMS ONLY					
Anterior/Posterior	11/79	13.9	10/68	14.7	0.91
Right/Left	3/11	27.3	1/19	5.3	0.14
Cephalad/Caudal	7/82	8.5	5/74	6.8	0.70
Total Shifts	19/82	23.2	16/74	21.6	0.85
Total ≥5 mm Shifts Only	17/82	20.7	11/74	14.9	0.43
BID	10/24	41.7	3/24	12.5	0.08
ROUTINE PORT FILMS ONLY					
Anterior/Posterior	29/335	8.7	21/310	6.8	0.41
Right/Left	1/38	2.6	2/91	2.2	0.88
Cephalad/Caudal	11/363	3.0	20/348	5.7	0.09
Total Shifts	43/348	12.4	32/363	8.8	0.17
Total ≥5 mm Shifts Only	40/348	11.5	28/363	7.7	0.11
≥6-MV Unit	15/114	13.2	8/197	4.1	0.007
4-MV Unit	28/234	12.0	24/166	14.5	0.52
BID	19/143	13.3	13/157	8.3	0.21
REQUESTED PORT FILMS ONLY					
Anterior/Posterior	10/107	9.3	7/83	8.4	0.84
Right/Left	1/11	9.1	0/14	—	0.27
Cephalad/Caudal	3/112	2.7	3/91	3.3	0.80
Total Shifts	13/112	11.6	10/91	11.0	0.90
Total ≥5 mm Shifts Only	13/112	11.6	9/91	9.9	0.73
BID	6/50	12.0	5/33	15.2	0.72
ALL PORT FILMS					
Anterior/Posterior	50/521	9.6	38/461	8.2	0.50
Right/Left	5/60	8.3	3/124	2.4	0.08
Cephalad/Caudal	30/542	5.5	19/528	3.6	0.15
Total Shifts	75/542	13.8	58/528	11.0	0.21
Total ≥5 mm Shifts Only	70/542	12.9	48/528	9.1	0.07
≥6-MV Unit	32/199	16.1	16/259	6.2	0.002
4-MV Unit	43/343	12.5	42/269	15.6	0.34
BID	35/217	16.1	21/214	9.8	0.09

when the technologists were asked to shift and repeat a port film, they might make an extra effort to ensure correct setup. Routine weekly port films were considered to be the best indicator of the reproducibility of the setup throughout treatment and were the primary focus of this analysis.

For each port film, the date, field orientation (e.g., right or left lateral, anterior or posterior), and the distance and direction of any requested isocenter shift were recorded. Observations with respect to the isocenter placement in the right to left direction were noted on the anterior and posterior port films. The anterior to posterior direction was noted on the lateral port films, and the cephalad to caudal direction was noted on all port films. The direction of the requested shift could not be determined on three oblique port films since concurrent "standard" orthogonal films were not available, (i.e., a right-left vs. anterior-posterior shift can not be determined in the absence of "standard" orthogonal films). If a shift was needed in more than one direction, each shift was recorded. Thus, it was possible to determine whether a misalignment occurred more frequently in one direction than another; however, for the purpose of scoring the *frequency* of isocenter misplacements, a shift in more than one direction was scored once. When the same misalignment appeared on multiple port films taken during the same treatment session, (i.e., a cephalad to caudal shift on both an anterior and a lateral port film) it was scored as only one event.

Differences between the frequency, type and magnitude of the shifts requested in the strip vs mask patient groups were compared with a two-tailed *chi*-square test.

RESULTS

One thousand five hundred and seventy-five port films representing 1070 independent isocenter placements were reviewed. The set-up reproducibility is compared for patients treated for head-and-neck and brain tumors immobilized using strips or masks in Tables 2, 3, and 4. Considering all films in all patients, there was no difference seen in the rate of requested isocenter shifts with the mask vs the strip system. For the patients treated on the ≥ 6-MV units, however, the frequency of isocenter shifts was 16.1% versus 6.2% with the strips and mask, respectively ($p = 0.002$). Almost all of the difference was seen in the routine films where the corresponding rates were 13.2% and 4.1% ($p = 0.007$). The frequency of requested isocenter shifts on routine films in the cephalad/caudal direction was 8.8% versus 2.0% with the strip and mask system, respectively ($p = 0.009$). The corresponding numbers for the anterior/posterior direction were 9.1% versus 2.4% ($p = 0.017$). Only one isocenter shift in the right/left direction was found in each group. For the patients treated on the 4-MV unit, no difference were seen.

Forty-three patients in this study had fields designed using a 3-D TP system. Since target margins were generally tighter in these patients, very small isocenter shifts were requested more frequently. Considering all films in the entire group, the frequency of isocenter shifts ≥5 mm was 12.9% with strips and 9.1% with the mask ($p = 0.07$). A similar, non-statistically significant trend was observed if only shifts ≥ 10 mm were considered ($p = >0.20$). Forty-two patients in this study were treated twice daily (Table 1) and had routine port films and isocenter assessment twice weekly. The data from this group is shown in Table 2.

Since the study period included patients treated during the implementation of the mask system, the impact of the treatment year on the number of requested isocenter shifts was considered in the masked group. The frequency of requested isocenter shifts was 3/23 (13%), 8/67 (11.9%), and 7/140 (5.0%) in 1991, 1992, and 1993, respectively ($p = 0.06$ for 1993 vs. sum of 1991 and 1992). Corresponding data for the strip immobilization system was not available since it had been in use approximately eight years prior to the study period. For the mask system, the frequency of requests for isocenter shifts on routine films was 4.1% (8/197) on the ≥ 6-MV units and 14.5% (24/166) on the 4-MV unit ($p = 0.0015$).

DISCUSSION

In this study, we compared the efficacy of two head-and-neck immobilization systems (3). Physician-re-

Table 3. Technical accuracy by type of immobilization for head and neck cancers only

	Strips		Mask		
	# isocenter shifts/ # times tested	Percent	# isocenter shifts/ # times tested	Percent	p-Value
INITIAL PORT FILMS ONLY					
Anterior/Posterior	8/39	20.5	7/32	21.9	0.91
Right/Left	2/5	40.0	0/6	—	0.15
Cephalad/Caudal	5/41	12.2	1/37	2.7	0.14
Total Shifts	14/41	34.1	8/37	21.6	0.36
Total ≥5 mm Shifts Only	13/41	31.7	7/37	18.9	0.32
ROUTINE PORT FILMS ONLY					
Anterior/Posterior	23/178	12.9	17/146	11.6	0.76
Right/Left	0/17	—	1/31	3.2	0.46
Cephalad/Caudal	14/186	7.5	7/189	3.7	0.13
Total Shifts	32/186	17.2	24/189	12.7	0.29
Total ≥5 mm Shifts Only	31/186	16.7	23/189	12.2	0.28
REQUESTED PORT FILMS ONLY					
Anterior/Posterior	6/78	7.7	6/59	10.2	0.64
Right/Left	1/5	20.0	0/6	—	0.30
Cephalad/Caudal	2/80	2.5	2/65	3.1	0.84
Total Shifts	9/80	11.3	8/65	12.3	0.86
Total ≥5 mm Shifts Only	9/80	11.3	8/65	12.3	0.86
ALL PORT FILMS					
Anterior/Posterior	37/295	12.5	30/237	12.7	0.97
Right/Left	3/27	11.1	1/43	2.3	0.15
Cephalad/Caudal	21/307	6.8	10/291	3.4	0.07
Total Shifts	55/307	17.9	40/291	13.7	0.23
Total ≥5 mm Shifts Only	53/307	17.3	38/291	13.1	0.22

Table 4. Technical accuracy by immobilization for brain tumors only

	Strips		Mask		
	# isocenter shifts/ # times tested	Percent	# isocenter shifts/ # times tested	Percent	p-Value
		Initial port films only			
Anterior/Posterior	3/40	7.5	3/36	8.3	0.90
Right/Left	1/6	16.7	1/13	7.7	0.60
Cephalad/Caudal	2/41	4.9	4/37	10.8	0.36
Total shifts	5/41	12.2	8/37	21.6	0.35
Total ≥5 mm shifts only	4/41	9.8	4/37	10.8	0.89
		Routine port films only			
Anterior/Posterior	6/157	3.8	4/164	2.4	0.49
Right/Left	1/21	4.8	1/60	1.7	0.45
Cephalad/Caudal	6/162	3.7	4/174	2.3	0.46
Total shifts	11/162	6.8	8/174	4.6	0.41
Total ≥5 mm shifts only	9/162	5.6	5/174	2.9	0.24
		Requested port films only			
Anterior/Posterior	4/29	13.8	1/24	4.2	0.28
Right/Left	0/6	—	0/8	—	—
Cephalad/Caudal	1/32	3.1	1/26	3.8	0.89
Total shifts	4/32	12.5	2/26	7.7	0.59
Total ≥5 mm shifts only	4/32	12.5	1/26	3.8	0.28
		All port films			
Anterior/Posterior	13/226	5.8	8/224	3.6	0.30
Right/Left	2/33	6.1	2/81	2.5	0.36
Cephalad/Caudal	9/235	3.8	9/237	3.8	0.99
Total shift	20/235	8.5	18/237	7.6	0.74
Total ≥5 mm shifts only	17/235	7.2	10/237	4.2	0.18

quested isocenter shifts were used as an indicator of setup reproducibility. A statistically significant reduction in the frequency of isocenter shifts was seen on the ≥ 6-MV units, but not on the 4-MV unit. This observation is likely due to differences in how the immobilization device was used on the different treatment machines. On the 4-MV unit, the base plate was not fixed to the couch (i.e., it had no "lip") (Fig. 1); therefore the setup was probably less reproducible. On the higher energy treatment machines, the base-plate lip facilitates a more reproducible set up of the immobilization system to the treatment couch. The use of a clamp prevents motion of the base plate on the treatment couch in all directions. Thus it appears that fixation of the immobilization device to the treatment table is a crucial component of reproducible immobilization. Towards this goal, we have further modified the system to include rigid clamping of the base plate to the treatment couch on all machines.

The lower rate of isocenter shifts in the masked patient group likely results from improved immobilization and more extensive field marking on the immobilization device. For patients immobilized in the mask, we generally placed a transverse and coronal line covering the anterior and both lateral aspects of the mask, to mark the planes that include the treatment isocenter. This is more extensive marking than was typically done for patients immobilized with the strips, wherein the marks were generally limited to the portion of the laser alignment lines that traversed the casting strips. Furthermore, patients immobilized in the strips often had marks on both the strips and their skin. This could lead to ambiguity at the time of patient setup, since the skin can move relative to the underlying structures; therefore, in a sense, some of the benefit of using the mask might lie in the reduced reliance on skin marks. This corresponds to a similar finding that we previously reported in regard to immobilization of patients with prostate cancer (2).

We choose to focus our comparison on the routine films since we believe, as described in the methods section, that these were the best indicators of treatment reproducibility. Our impression that the frequency of isocenter shifts on initial films might be increased due to differences in the laser, couches, geometries, etc. (see methods) was corroborated by the relatively high rate of isocenter shifts seen on initial films with both the mask and strips.

The apparent benefit derived from the use of the mask has increased with time. In 1991, when the mask was first introduced to our clinic, the rate of isocenter shifts was 13%. This decreased to 5% in 1993, likely reflecting improvements over time in the overall system and increased physician and technologist acceptance of the newer immobilization device.

The time required to make the head immobilization systems compared in this report is approximately the same. While there are modest increased costs related to the construction of the customized head support and face mask, this should be weighed against the gains realized by patient comfort and the reduced number of port films that need to be taken, developed, and reviewed. Increasing the accuracy of daily treatment provides an opportunity for improving the therapeutic ratio by increasing tumor control and reducing normal tissue reactions.

In conclusion, the more aggressive head and neck immobilization system described, including a custom made head rest and face mask, produces improved patient repositioning provided that the immobilization system is fixed to the treatment couch.

REFERENCES

1. Barish, R. J.; Lerch, I. A. Patient immobilization with low-temperature splint/brace material. Radiology 127:548; 1978.
2. Bentel, G. C.; Marks, L. B.; Sherouse, G. W.; Spencer, D. P.; Anscher, M. S. The effectiveness of immobilization during prostate irradiation. Int. J. Radiat. Oncol. Biol. Phys. 31:143–148; 1995.
3. Bentel, G. C.; Marks, L. B.; Sherouse, G. W.; Spencer, D. P. Customized head immobilization system. Int. J. Radiat. Oncol. Biol. Phys. 32:245–248; 1995.
4. Devereux, C.; Grundy, G.; Littman, P. Plastic molds for patient immobilization. Int. J. Radiat. Oncol. Biol. Phys. 1:553–557; 1976.
5. Gerber, R. L.; Marks, J. E.; Purdy, J. A. The use of thermal plastics for immobilization of patients during radiotherapy. Int. J. Radiat. Oncol. Biol. Phys. 8:1461–1462; 1982.
6. Goldson, A. L.; Young, J.; Espinoza, M. C.; Hensche, U. K. Simple but sophisticated immobilization casts. Int. J. Radiat. Oncol. Biol. Phys. 4:1105–1106; 1978.
7. Hauskins, L. A.; Thompson, R. W. Patient positioning device for external-beam radiation therapy of the head and neck. Radiology 106:706; 1973.
8. Jones, D.; Hafermann, M. D. A radiolucent bite-block apparatus. Int. J. Radiat. Oncol. Biol. Phys. 13:129–132; 1987.
9. Lewinsky, B. S.; Walton, R. Lightcast. An aid to planning, treatment, and immobilization in radiotherapy and research. Int. J. Radiat. Oncol. Biol. Phys. 1:1011–1015; 1976.
10. McCullough, E. C.; McCullough, K. P. Improving agreement between radiation-delineated field edges on simulation and portal films: the edge tolerance test tool. Med. Phys. 20:375–376; 1993.
11. Niewald, M.; Lehman, W.; Uhlmann, U.; Schnabel, K.; Leetz, H. K. Plastic material used to optimize radiotherapy of head and neck tumors and the mammary carcinoma. Radiother. Oncol. 11:55; 1988.
12. Rosenman, J.; Roe, C. A.; Cromartie, R.; Muller, K. E; Pizer, S. M. Portal film enhancement: technique and clinical utility. Int. J. Radiat. Oncol. Biol. Phys. 25:333–338; 1993.
13. Rosenthal, S. A.; Galvin, J. M.; Goldwein, J. W.; Smith, A. R.; Blitzer, P. H. Improved methods for determination of variability in patient positioning for radiation therapy using simulation and serial portal film measurements. Int. J. Radiat. Oncol. Biol. Phys. 23:621–625; 1992.
14. Sørenson, N. E.; Sell, A. Immobilization, compensation and field shaping in megavoltage therapy. Acta Radiol. Ther. Biol. Phys. 11:129–134; 1972.
15. Wang, C. C.; Boyer, A.; Dosoretz, D. A head holder for treatment of head and neck cancers. Int. J. Radiat. Oncol. Biol. Phys. 6:95–97; 1980.