Preliminary clinical study on brass compensator-based intensity-modulated radiation therapy

ABSTRACT

Objective: The objective of this study is to preliminarily evaluate the feasibility of brass compensator-based intensity-modulated radiation therapy (CB-IMRT).

Materials and Methods: Ten patients (three cases of nasopharyngeal cancer, four of esophageal cancer, and three of rectal cancer) who underwent an IMRT treatment planning were selected for this study. The transmission coefficient of brass plates with different thicknesses was measured under a 6 MV photon beam used in the treatment planning system, and the equation for thickness computation was fitted out. The plan file RTPLAN file of each patient was exported from the planning system and transformed to a compensator thickness matrix; therefore, it was input into a numerical control machine for the manufacturing and cutting of the compensators. The CB-IMRT plans obtained were verified on a homogeneous phantom with commercial software. Planar doses were measured by films, and the computed ones were compared using gamma evaluation with 3-mm distance to agreement and 3% dose difference criteria adopting a pass rate of \( \gamma \geq 90\% \). The monitor units (MUs) of the multileaf collimator IMRT plan (MLC-IMRT) and the CB-IMRT plans were compared. Depth of cut was computed through the equation fitted from real measurements. The planned RTPLAN files were used to transform the cutting files needed by the numerical control machine.

Results: Plan validations show that the minimum and maximum of gamma pass rate among the 10 patients are 90.2% and 98.2%, respectively, which both satisfy the requirements of clinical planning. The MUs of CB-IMRT are significantly smaller compared with MLC-IMRT.

Conclusion: CB-IMRT satisfies the requirements of clinical therapy and can be used in a radiotherapy routine.

KEY WORDS: Brass compensator, intensity-modulated radiation therapy, \( \gamma \) analysis

INTRODUCTION

The most common techniques available today for delivering intensity-modulated radiation therapy (IMRT) treatments on linear accelerators use multileaf collimators (MLC). For some accelerators without MLC, IMRT can be achieved installing MLC at the exit of the gantry, but this way is both. An alternative way to deliver the intensity-modulated treatment is using physical compensators. Compensator-IMRT converts the open field uniform fluence map through a custom-made compensator that is often manually placed in the wedge or block holder of the treatment machine. They have been used in radiotherapy for decades to produce simple forms of intensity modulation. The obvious advantage of this IMRT delivery method is its simplicity. The static nature of the compensator intensity modulation simplifies the treatment delivery, dose computation, and thus, the quality assurance (QA) procedure. Intensity modulation can be performed with higher resolution and smoother dose distribution, consequently, problems originating from patient movement can be minimized. Furthermore, the monitor unit (MU) can be reduced because multiple segments are unnecessary. One obvious drawback of most of the compensator-IMRT techniques is the lack of automation. Radiation therapists need to go into the treatment room and exchange customized compensators between treatment fields. Many studies related to the use of compensator-based IMRT have been performed.
in the past decades,[10-13] in this study, we developed the brass compensator-based IMRT technique for an accelerator without MLC systems.

MATERIALS AND METHODS

Clinical cases
Ten patients, 3 nasopharyngeal (NP), 4 esophageal (E), and 3 rectal cancer (R) cases who underwent an IMRT treatment were enrolled for this study. A Siemens Primus-H accelerator mounting an MLC implemented in Oncentra (Version 4.3) treatment planning system (TPS) (Nucletron B.V, The Netherlands) was used at this purpose. A 6 MV photon beams energy with seven or five beam arrangements was used for NP, R, and E treatments, respectively.

Setup of brass plate
Brass plates (density 8.40 g/cm³) of different thicknesses were used for this study. Their transmission coefficient was computed under a 6MV Siemens Primus photons beam. Brass plates with different thicknesses (1, 2, 5, 10, 20, and 50 mm) were made at this purpose. Brass plate or plate combinations with thicknesses of 0, 1, 2, 5, 7, 10, 20, 30, 40, 50, 60, 70, 80, 100, or 120 mm were placed on the accelerator’s block tray. The measurements for the evaluation of the transmission coefficient of brass plates were performed in a water phantom with a PTW 0.6 cm³ thimble ionization chamber placed at the isocenter in water at a depth of 10 cm as the depth of absolute dose evaluation following the protocol IAEA TRS-398.[16] The previous studies confirmed the suitability of this depth for the evaluation of the transmission coefficient.[17] A PTW UNIDOS dosimeter was used to collect data. Since the radiation field does not largely affect ray transmission, all measurements were conducted for a 5 cm × 5 cm field size. For each brass plate thickness, the measurements were repeated several times and the average transmission coefficient was used. Indicating the measured transmission by Y and the brass thickness by x, the function

\[ Y = Ae^{-\mu x} \]  

(1)

Was used, and the parameters A and \( \mu \) were figured out using the measurements performed and applying the least squares method. In Figure 1, the flow chart of the interface transformation between TPS and the computer numerical control machine (CNC) is illustrated.

The RTPLAN files of the patients were exported from the TPS and analyzed. For each field, the segment-related information, such as the MLC leaf position and MU under each segment was read. The effective field was divided into grids with a 3 mm × 3 mm resolution, and the MUs of each grid center were computed. Under segment \( F_i \), if the grid's center \( P_i \) was not shielded out by the MLC leaves, then the MUs of this segment were considered for \( P_i \), otherwise zero MUs were allocated. The MUs of central point \( P_i \) under all segments \( F_i \) were summed up, resulting in the total MU of \( P_i \). The total monitors unit for of each grid center was computed, and a MU matrix was determined.

The MU matrix is transformed by the function previously fitted out to a compensator thickness matrix. If the thickness at a point, as computed, is greater than maximum thickness available among all compensators, the maximum thickness available will be setup at this point.

The thickness matrix was then transformed into brass compensator processing file (.igs). IGS files are a type of initial graphics exchange specification 2D or 3D vector graph files. IGS files can save and output vector data criterion based on ASCII and are commonly used in computer-assisted design software. IGS files can store wire-frame models, surfaces or solid objects, and circuit diagrams or other objectives.

The transformed compensator files were delivered to the CNC, where they were cut by brass lumps into predesigned finished products. The finished compensators were examined point-by-point with by laser testing equipment (LS-3032, KEYENCE, China) and compared with the preset processing files. A processing precision > 0.1 mm was achieved. The compensators were installed on special trays, which were inserted into the slots of the accelerator’s wedge plates. The opening side of the compensator was placed downward.

Plan verification
For the plans’ QA verification, the dose distribution of each IMRT plan (compensator-based [CB] based) was recalculated on the CT scan of a standard PMMA homogeneous phantom (RW3, IBA Dosimetry), consisting of 30 PMMA slabs, 30 cm × 30 cm × 30 cm size, 1 cm thick; each field of the treatment planning was set up at a zero-gantry angle. Measurements were performed with GAFCHROMIC™ EBT3 films (sheet dimensions 20.3 cm × 25.4 cm) aligned with the edge of the middle layer of the phantom laid flat and parallel to the couch top. Film scanning was performed with a vertical bed scanner Vidar VXR-16 (VidarSystems Corporation,
Herndon, VA, USA), and the films were analyzed with the PTW VeriSoft software (Freiburg, Germany). The films had first been calibrated within their range of sensitivity (10–800 cGy). For this purpose, a calibrated ion chamber, Farmer chamber 0.6 cm$^3$ (PTW-Freiburg, Germany), was inserted in the phantom below the film plane to check the linac output during the irradiation process and to determine the dose delivered to the film by applying the IAEA-TRS 398 protocol. Measured dose data from delivering the treatment fluence map on the homogeneous phantom and calculated planar dose distributions were compared using gamma evaluation with 3 mm distance-to-agreement and 3% dose difference end points. We strive to reach $\gamma \geq 90\%$ (i.e., the percentage of points with $\gamma < 1$ that must be $>90\%$). The total MUs of the MLC-IMRT and CB-IMRT techniques were compared.

**RESULTS**

The transmission curve of brass plates was reported in Figure 2. A comparison of the computed and measured transmission coefficient for different thicknesses of brass plates, randomly selected, was performed; for this purpose, we defined the error of the transmission coefficient as the measured minus the calculated over the calculated one. The results are reported in Table 1 and shown in accordance within 1%.

In Figure 3, the fluence map coming from a CNC machine [Figure 3a] and its corresponding 3D brass compensator are illustrated [Figure 3b]. The compensator obtained for esophageal case 2 is shown in Figure 4. The validation of the whole procedure starting from the fluence maps of the TPS and ending on physical manufactured brass compensators will be assessed with a gamma-index analysis. The results are reported in Table 2. The gamma passing rates with acceptance criteria 3%/3 mm of each patient satisfy the clinical requirements ($P_{\gamma} > 90\%$). The lowest gamma passing rate is 90.2%, and the highest rate is 98.2%. In Figure 5, an example of a gamma-index analysis for one case is reported.

The MUs coming from the optimization of the MLC-IMRT treatment planning, and the MU effectively calculated for the BC-IMRT plan were compared. Table 2 shows that the MUs of BC-IMRT were significantly smaller compared with MLC-IMRT. The mean increase of MUs was 22, 57, and 240 MU for the R, E, and NP treatments, respectively. The delivery time of the CB-IMRT considering a dose rate of 400 MU/min is quite short if compared with the delivery time of an MLC treatment where the duration is strongly dependent on the leaf movement. For the NP cases, the mean spare of MU is around 240 which

![Figure 2: Transmission curve of brass plates](image)

**Table 1**: Computed and measured transmission coefficient for different thickness of brass plates and their relative percentage errors are reported in columns 2, 3, 4, respectively (error)

| Thickness (mm) | Computed | Measured | Error (%) |
|---------------|----------|----------|-----------|
| 13            | 0.615    | 0.619    | 0.65      |
| 34            | 0.292    | 0.294    | 0.68      |
| 55            | 0.143    | 0.143    | 0.00      |
| 66            | 0.100    | 0.099    | -1.00     |
| 87            | 0.051    | 0.051    | 0.00      |

**Table 2**: Results of the gamma-index analysis passing rate for the brass compensator-intensity-modulated radiation therapy cases, and monitor unit comparison between the compensator-based intensity-modulated radiation therapy and multileaf collimators-intensity-modulated radiation therapy treatment planning for the four esophageal cases (E1-E4), the three nasopharyngeal (NP1-NP3), and the three rectal (R1-R3) cases studied

| Cases | Pass rate (%) | MU |
|-------|---------------|----|
|       | MLC | BC |
| E1    | 94.1 | 716 | 653 |
| E2    | 94.5 | 699 | 657 |
| E3    | 93.2 | 678 | 630 |
| E4    | 92.3 | 681 | 607 |
| NP1   | 90.2 | 1860 | 1561 |
| NP2   | 91.9 | 1794 | 1519 |
| NP3   | 92.9 | 1814 | 1577 |
| R1    | 98.2 | 564 | 537 |
| R2    | 99.8 | 412 | 393 |
| R3    | 97.4 | 533 | 514 |

MU=Monitor unit, MLC=Multileaf collimators, E=Esophageal, NP=Nasopharyngeal, R=Rectal cancer, BC=Brass compensator

![Figure 3: The fluence map coming from the computer numerical control machine (a) and his corresponding finished three-dimension brass compensator (b)](image)
considering the time to enter in the treatment room and change the brass plate may lead to a final duration treatment comparable with the MLC ones.

**DISCUSSION**

Through the whole process, CB-IMRT can be affected by multiple factors. (1) Material selection and compensator manufacture: among various materials for the manufacturing of compensators, the commonly used types include Cerrobend lead alloy, brass, and tungsten. These materials have specific merits and drawbacks. Materials in the clinic should be selected from perspectives of practicability, workability, and economy. In our preliminary study, we selected the low melting point lead alloy and achieved high effect. On the other hands, under 6 MV photon beam, the half-value layer of brass is very small, and therefore the transmissivity largely changes within a small depth range (usually ≤1 mm); the use of very high-precision machine is mandatory. (2) The change of X-ray quality and output factor: in this study, we did not consider either the changes of dose calculation due to changes of photon quality after rays pass through brass compensators, or the changes of output factor induced by compensators. The dose verification results of the 10 cases show that these changes are within acceptable ranges. However, as reported, with a large field view (≥15 cm × 15 cm) and when the route of rays passing through compensation materials is >5 cm, the error of single-point dose is up to 7%. Thus, in the future studies, the influence of this factor should be considered. (3) Optimization of IMRT plan: CB-IMRT does not require any specific planning, and thus, the existing clinical planning systems are all suitable. Planning systems of some brands can be directly transformed into compensator files, but not all patterns are acceptable. In practice, software can be designed as per specific situations and used to transform the RTPLAN files into files needed by the CNC. The optimization of IMRT planning is basically consistent with that of MLC-IMRT, but the difference is that it does not restrict the number of segments. Thus, the results can be optimized by increasing the number of segments. Moreover, a smaller distance between dose calculation points is better, but given the calculation time and real cutting and processing precision, a distance of 3 mm is satisfactory in clinic. After a period of clinical use, we can state that CB-IMRT presents some advantages: it can be used on the old facilities (linac without MLC), which is favorable for the popularization of IMRT; lower MUs are necessary, and there is a high repeatability in the daily treatment, with no restriction on field’s size which avoids the connection after splitting field. It also has some drawbacks: manufacturing compensators are very complex and time-consuming; and during irradiation, compensators should be exchanged field by field, which increases the workload of therapists. However, a group reported that the special device could change compensators automatically. For CB-IMRT, the QA flow in the clinic is basically consistent with routine IMRT techniques. The only unique QA measure is that the compensators after manufacture should be validated in terms of cutting depth. In other words, laser measuring tools are needed to validate whether the cutting error is within ±0.5 mm. This step is usually taken in processing factories; a recent study implemented the use of a 3D printer to create intensity-modulated radiotherapy compensator blocks; whereas the recent researchers used gel dosimetry for dose-volume histogram verification. Other important and practical concerns can be addressed for a successful compensator-based IMRT procedure, for example, intrafraction motion and the evaluation of peripheral and...
surface dose. Currently, many researchers are being carried out to manage these uncertainties,\cite{12,25-28} which are beyond the scope of this study.

**CONCLUSION**

Brass-made IMRT compensators satisfy the treatment requirements in clinic, thus, CB-IMRT can be used as a supplement to MLC-IMRT under specific conditions.

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**Conflicts of interest**

There are no conflicts of interest.

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