Corrugated Fiberboard as a Positioning Insert for Patients Undergoing Radiotherapy

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Tri-wall corrugated fiberboard/Carbon-fiber base plate/Patient-positioning insert/Body immobilization device.

We have developed a new body fixation system for single patient use, which consists of a vacuum cushion, a thermoplastic fixation sheet which is used to suppress involuntary and voluntary patient movement, and a tri-wall corrugated fiberboard base plate to which both the vacuum cushion and the thermoplastic sheet are affixed. To evaluate the characteristics of the fiberboard as a patient-positioning insert, the photon beam attenuation of a fiberboard base plate, a carbon-fiber base plate, and a vacuum-formed cushion were compared. The strength of the fiberboard was also evaluated. The attenuation for the carbon-fiber base plate was 3.7% and 2.6% in 4 MV and 10 MV photon beams, respectively, while the results were less for the fiberboard base plate, i.e. 1.9% and 1.6%. The vacuum-formed cushion had a minimal effect on transmission. None of the materials subsided under the weight loading of 20 g/cm². There was no difference between the thicknesses of the fiberboard before and after a 50 times daily load with the 60 kg weight of a volunteer. Corrugated fiberboard is a robust and low attenuating material that functions well as a patient-positioning insert.

INTRODUCTION

For the adoption of precise radiotherapy, including intensity-modulated radiotherapy or stereotactic radiotherapy, high precision in patient positioning is essential.1) In addition, many radiation oncologists recognize the need for patient immobilization during treatment, especially because the treatment time for precise radiotherapy has become longer than that generally required for conventional radiation techniques. As for the head and neck fixation, traditional methods have been replaced by modern materials such as carbon-fiber support plates, a vacuum cushion, and thermoplastic materials.2) A body immobilization system such as a fixation system based on double-vacuum technology3) or a body cast system using a carbon fiber base plate4) has also been developed, but these devices have been found to be complicated and expensive.

Corrugated fiberboard is a paper-based construction consisting of corrugated “medium” sandwiched between layers of flat linerboard. In particular, tri-wall corrugated fiberboard is a stronger structure than conventional single- or double-wall corrugated board. Accordingly, tri-wall corrugated fiberboard has been used in a broad range of industries for its strength, flexibility, and environmental friendliness. However, it has rarely been reported as a material for patient fixation devices.

We have developed a new body fixation system, which consists of a vacuum cushion, a thermoplastic fixation sheet which is used to suppress involuntary and voluntary patient movement, and a tri-wall corrugated fiberboard base plate to which both the vacuum cushion and the thermoplastic sheet are affixed. The aim of this study is to investigate the characteristics of the fiberboard base plate as a patient-positioning insert in external radiotherapy.

MATERIALS AND METHODS

Fiberboard base plate

A home-made fiberboard base plate was evaluated. The base plate was composed of two-ply tri-wall corrugated fiberboard (HiPLE-ACE, Oji Interpack, Tokyo, Japan) to increase its strength (Fig. 1).
Patients can be positioned in a vacuum–formed cushion on the plate. A thermoplastic fixation sheet can also be attached using a hook and loop fastener system. Using an arm support or a knee support, the system can be utilized in the treatment of chest or pelvic lesions (Fig. 2).

To compare the characteristics of materials as an insert between the treatment tabletop and the patient, carbon-fiber base plate (ESN-1800, Engineering system, Matsumoto, Japan), and vacuum–formed cushion (ESF-19D, Engineering system, Matsumoto, Japan) were also evaluated in this study (Table 1).

### Attenuation measurement

All attenuation measurements were made with an ionizing chamber (PTW30013, PTW, Freiburg, Germany) in a solid water phantom on a linear accelerator (Mevatron KD2 Primus, Siemens, Germany) using photon energies of 4 and 10 MV. A standard geometry of 10 × 10-cm fields, an SAD = 100 cm, was used for all measurements. The material was placed in direct contact with the surface of the phantom. The angle of the beam was perpendicular to the material. The chamber was placed at a depth of 10 cm directly under the part to be measured using the room lasers for alignment. A total of 100 monitor units were delivered. The attenuation was calculated as one minus the ratio of the ionization measured at the reference depth with and without the material on the surface of the phantom.

### Measurement of the strength of the materials under weight loading

To evaluate the strength of the material under weight loading, changes in the position of the solid water phantom (35 × 35 × 20 cm³) on the material were measured using a commercially available high-speed machine vision system (CV-3000, Keyence, Osaka, Japan). This machine vision system was composed of a 2,000,000-pixel color CCD camera and computerized control systems. The CCD camera was positioned 1.5 m from the phantom on the materials (Fig. 3a). External fiducials were placed on the phantom, and the image data obtained from the fiducials were captured onto the CCD, converted to digital data within the camera.

### Table 1. Characteristics of the materials used in the study.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Thickness (cm)</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiberboard base plate</td>
<td>3.2</td>
<td>0.131</td>
</tr>
<tr>
<td>Carbon-fiber base plate</td>
<td>3.0</td>
<td>0.339</td>
</tr>
<tr>
<td>Vacuum-formed cushion</td>
<td>5.0</td>
<td>0.027</td>
</tr>
</tbody>
</table>

The vacuum-formed cushion was examined after a vacuum pressure of 300 mmHg for five minutes was applied. Densities were calculated from the relation between the material’s real weight and its volume.
unit, and transferred to the controller, after which the position of the fiducials was calculated to an accuracy of < 0.1 mm.\textsuperscript{5,6} The positions of the fiducials (i.e., the position of the phantom) were calculated at 0, 5, 10, 15, and 20 min after loading weight of the phantom. The measurement was repeated 3 times and average values were taken.

**Measurement of the thickness of the fiberboard base plate after iterative weight loading**

The thickness of the fiberboard base plate was evaluated before and after a 50 times daily load of approximately 10 minutes with the 60 kg weight of a volunteer. Because the volunteer was positioned in a vacuum–formed cushion, the body weight was considered to be distributed evenly on the plate. The board thicknesses were measured on the CT images by using a digital ruler in a treatment planning system (XiO, CMS, St. Louis, MO). The images acquired had a pixel size of 0.9 mm × 0.9 mm, and the ruler had a resolution of 0.1 mm. The measurements were repeated at five different points at the center, the right periphery, and the left periphery of the board, and average values were taken.

**RESULTS AND DISCUSSION**

The attenuation properties of the different materials are shown in Table 2. The attenuation values for the carbon-fiber base plate were 3.7% and 2.6% in 4 MV and 10 MV photon beams respectively, while the results were less for the fiberboard base plate, i.e. 1.9% and 1.6%. The vacuum–formed cushion had a minimal effect on transmission.

The changes in position of the solid water phantom on the materials are shown in Fig. 3(b). None of the materials examined subsided under the weight loading of 20 g/cm\textsuperscript{2}, which is almost equal to the weight loading of the body with a thickness of 20 cm.

The changes in thickness of the fiberboard before and after a 50 times daily load with the 60 kg weight of a volunteer are shown in Table 3. There was no difference between the thicknesses of the board before and after iterative weight loading.

For optimum daily use in the treatment room, an immobilization system should be (a) accurate but simple, (b)...

**Table 2.** 4 MV or 10 MV X-ray attenuation results for various materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>4 MV</th>
<th>10 MV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiberboard base plate</td>
<td>1.9%</td>
<td>1.6%</td>
</tr>
<tr>
<td>Carbon-fiber base plate</td>
<td>3.7%</td>
<td>2.6%</td>
</tr>
<tr>
<td>Vacuum-formed cushion</td>
<td>0.2%</td>
<td>0.1%</td>
</tr>
</tbody>
</table>

**Table 3.** The thickness of the fiberboard base plate before and after iterative weight loading.

<table>
<thead>
<tr>
<th>Location</th>
<th>Before weight loading (cm)</th>
<th>After weight loading (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center</td>
<td>3.2</td>
<td>3.2</td>
</tr>
<tr>
<td>Right periphery</td>
<td>3.3</td>
<td>3.3</td>
</tr>
<tr>
<td>Left periphery</td>
<td>3.2</td>
<td>3.3</td>
</tr>
</tbody>
</table>
portable and light-weight, (c) adaptable for the treatment of many lesions, (d) comfortable, (e) inexpensive, and (f) radiolucent. The fiberboard immobilization system described here meets these criteria. In addition, fiberboard is easy to handle and is an environmentally friendly solution.

The high strength and low density of triple-wall corrugated fiberboard suggest an excellent material with minimal attenuation for a support plate on a treatment table. Using triple-wall corrugated fiberboard, we have created a body fixation system (Fig. 2). Unlike other body immobilization devices, this system consists not only of a vacuum cushion, but also of a thermoplastic fixation sheet which is used to suppress involuntary and voluntary patient movement, and a fiberboard base plate to which both the vacuum cushion and the thermoplastic sheet are affixed. This system may be applicable to the treatment of lesions in various sites, because all components of this system consist of low attenuating materials as shown in Table 2. However, it should be noted that the transmission depends on beam angle. We recommend that the transmission through this system should be accounted for, for example, incorporating this system directly into the planning process.

Compared to the rigid fixation system using carbon fiber, the fiberboard base plate may be less durable and less rigid. Because the permanence of this board has not been proven, we consider this system to be appropriate for single patient use. Although this non-rigid system may potentially reduce reproducibility compared with the system using a carbon-fiber base plate, if a careful analysis of patient positional reproducibility is performed using image-guided radiation techniques, we can use it easily and effectively on our patients. Although it is not well known that the fixation system incorporating a body compression element influences intrafraction or interfraction motion of the target, we believe that suppression of involuntary and voluntary patient movement is essential in precise radiotherapy. This subject is under investigation.

ACKNOWLEDGMENTS

Authors thank Mr. Shuhei Fukui (IMARI Co., Ltd.) for technical supports. This study was supported in part by KAKENHI (No. 18591383), and also by a grant from the Ministry of Health, Labor and Welfare of Japan.

REFERENCES


Received on June 22, 2009
Revision received on July 28, 2009
Accepted on August 4, 2009
J-STAGE Advance Publication Date: September 16, 2009