Original Article

Effects of artificial structures on postoperative irradiation therapy
—Skull reconstruction case—

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Summary

Purpose: The radiation therapy is often followed by neurosurgery including cranial reconstruction, in which titanium plates are used. Thus, it was investigated whether titanium plates for skull reconstruction may affect the dose.

Materials and Method: A titanium plate was placed in a phantom with 160 mm in depth and the doses were measured after unidirectional irradiation and/or opposing portal irradiation by the chamber method and film method.

Results: Dose changes with the plate in unidirectional irradiation were −0.9%, +6.6%, +1.4% and 0% at 0 mm, 10 mm, 15 mm and 80 mm from the surface of irradiation side, respectively. Changes in dose towards the center ranged from +3.5 to −2.1%.

Conclusion: Changes in radiation dose from use of a titanium plate in cranial reconstruction were within a range that would not affect post-operative radiation therapy.

Introduction

A number of artificial structures are used in surgery and other medical treatments in many location and objectives. Previously, many reported the similar effects of metal implants on following radiation, such as in plate reconstruction for oral cavity, maxillary bone reconstruction. The maxillary bone and other bones may be subjected to loads due to movement and require durability, the materials used for implants in addition to titanium include stainless steel, palladium and other metals. Recently, titanium products are used for reconstructive treatment in a wide range of areas including limbs, chest wall and oral cavity. Depending upon the material and locations, these structures may interfere with later treatment including irradiation treatment is not an exception.

In neurosurgery, there are frequent applications of postoperative irradiation therapy and thus, we investigated whether of skull reconstruction using a titanium plate affect the effectiveness of irradiation therapy dose.

Materials and Methods

The titanium plate was 0.8 mm thickness medical pure titanium bone (Bear Medic. Co., Japan). The irradiation apparatus used was a medical accelerator: Mevatron KD Primus (Siemens, USA).

The used measurement tools show: Solid Water phantom (Gamme, USA), Kodak EDR-2 Film, Fuji-densitometer model no. 301 (The X-RITE co., Japan). Dosimeter/ionization chamber: C-134 (Ohyo-Giken, Japan). This equilibrium flat plate type dosimeter was used for dose measurements on skin surfaces.

Key words: Titanium plate, Reconstruction, Radiation dose
Fig. 1  Titanium plate and image of titanium plate fitted on dry skull.

Fig. 2  Experimental Apparatus for these studies 1 & 2
The chamber method was used to compare the doses with or without a titanium plate in unidirectional irradiation (experiment 1) and opposing portal irradiation (experiment 2). The irradiation condition was in common for both, 10 MV x-ray, 200 MU preset, field size $10 \times 10$ cm, 160 mm skull thickness between two 10 mm thickness skin phantoms, thus the center of intracranial region was 80 mm ($\star$), SSD was fixed at 920 mm. 17 measurement points were set from 0 mm (skin surface) to 160 mm (opposite skin surface).

**Experiment 1 & 2 (Figure 2)**

Measurements were made using the chamber method to assess changes in doses due to direction dependence.

Unidirectional (Experiment 1) and opposing portal irradiation (Experiment 2) were conducted. The irradiation condition was in common for both, 10 MV x-ray, 200 Monitor unit; MU preset, field size $10 \times 10$ cm, 160 mm skull thickness between two 10 mm thickness skin phantoms, thus the center of intracranial region was 80 mm ($\star$), source-surface distance: SSD was fixed at 920 mm. 17 measurement points were set from 0 mm (skin surface) to 160 mm (opposite skin surface) and source-target distance: STD was changed every time. The titanium plate was set beneath the skin phantom on the surgery side. The C-134 chamber was set perpendicular to the axis of the x-ray at each measurement point from the skin surface to the center of the intracranial region. Each measurement was conducted three times.
Experiment 3 & 4 (Figure 3)

Next, measurements were made using the chamber and film method to assess changes in dose in the built up areas limitation.

The chamber method was used to make the measurements were set from 0 mm to 35 mm below the plate. The film method was used to measure the Depth-Dose curve for the hospital’s treatment apparatus. The film was placed at the 28 mm peak depth for this apparatus and the MU was varied to expose films. The density of the films and dose were used to produce the Depth-Dose curve. The plate was placed directly on the film (0 mm) and the measurement points were set at 1 mm intervals from 0 mm to 35 mm. The conditions for the two treatments were SFD fixed at 1,000 mm, field size was 10 × 10 cm, 10 MV x-ray and MU value was 200 MU.

Results

Experiment 1 (unidirectional irradiation method)

(Figure 4)

At this present notice, 0 mm was show of skin surface.

Peak dose without plate and with plate was found as 220.7 cGy & 218.8 cGy at 25 mm depth from the skin surface, respectively, a difference of −0.9%. Dose without plate and with plate at brain center at 80 mm depth was found as 175.1 cGy & 175.1 cGy, no difference. Plate outside dose (10 mm) was 189.1 cGy and 201.5 cGy, a difference of +6.6%. At 15 mm depth dose of plate outside, measured dose was 210.8 cGy and 213.7 cGy, a difference of +1.4%. Changes in dose towards the center ranged from −2.3 to −0.5%.

Experiment 2 (opposing portal irradiation method) (Figure 4)

At this present notice, 0 mm was show of brain center point.

Dosage profiles were found as trapezoidal in both with and without the plate at add up of doses by opposing portal irradiation method.

Peak dose without and with plate was found as 178.1
cGy at $-/+50$ mm depth and 1769 cGy at $-/+45$ mm depth for plate side from the brain center.

For the opposite side, peak dose without and with plate was found as 178.1 cGy at $-/+50$ mm depth and 174.9 cGy at $-/+55$ mm depth for plate side from the brain center, a difference of $-1.8\%$. At the skin level, the doses at $-/+80$ mm depth the dose without and with the plate was found as was 175.1 cGy & 172.3 cGy, a difference of $-1.6\%$.

Around the plate, at $-/+70$ mm depth (outside the plate), the dose without and with the plate was found as was 157.5 cGy & 163.0 cGy, a difference of $+3.5\%$.

And measured dose at $-/+65$ mm depth (inside the plate) the dose without and with the plate was found as was 169.9 cGy & 170.1 cGy, a difference of $+0.1\%$. Differences in total dose with the plate compared to without the plate ranged from $+3.5$ to $-21\%$.

Experiment 3 & 4 (Figure 5)

The dose increased up to 10 mm and then keep plateau for the two measurement methods. This was consistent with the beam data for the treatment apparatus used in these experiments. Similar trends were observed for dose in the built up area from 10 mm depth below the plate, especially up to 5 mm using the chamber method and film method with significant differences in dose being observed.

Discussion

The first factor considered was the use of medical grade pure titanium as the material for the bone substitute. As the density of the pure titanium plate skull substitute is $4.54^{18}$ (g/cc), it has higher x-ray absorption and scattering occurs in front of and in back of the plate. This resulted in increased radiation dose around the plate for unidirectional and opposing portal irradiation methods ranging from $+0.1$ to $+6.6\%$. There was no SD. With increasing distance from the titanium plate, the scattering gradually decreased and the absorption also showed a weakened.

Previously many reports and these reports focus mainly on assessment of durability while those that consider effects on dose includes ones recommending the use of metal implants to support soft tissues$^{15,18}$. In craniocervical surgery, the bone structure is an area including various cavities such as the oral and pharyngeal nasal cavity. With regards to the use of
metals other than titanium, Mimura\textsuperscript{17,19} reported that palladium plates for dental disease resulted in a maximum 150% change in dose at 5 mm behind the plate due to the effect of x-ray scattering. Similarly for stainless plates\textsuperscript{20}, the scattering on dose at 4 to 10 mm inside the plate was observed, and this was reduced by the use of opposing portal irradiation. This is similar to the results observed in our study where opposing portal irradiation compensated for the reduction in dose with depth observed with unidirectional irradiation.

Tamada\textsuperscript{20} reported that the use of stainless steel stents used in the treatment of biliary duct diseases resulted in a +17.2% increase in dose behind the metal stent. Similar Tsuji\textsuperscript{21} reported the use of covered stainless steel stents to treat biliary diseases resulted in a +8.2% increase in dose. This indicates that the metal composition, structure and implantation location are factors affecting dose.

Next, the effect of radiation quality was considered.

Allal et al\textsuperscript{22} considered the type of radiation source as a factor in the effect of metal plates. For the case when 6 MV x-rays were used, the dose at the plate surface on the radiation source side changed by +1 to +11% while the dose on the backside changed by +5 to +8%. When cobalt 60 was used, the dose on the plate surface changed by +3 to +7% while the dose on the backside changed from +4 to +8%. In other reports for 6 MV x-rays, there is wide variation in the changes in dose with one report of +17 to +23%\textsuperscript{17} while another reporting +12% in front of and −50% behind\textsuperscript{20}. These were all larger changes than were observed in this study using 10 MV x-rays. That peak doses were observed at 20 to 30 mm from the skin surface is considered to be appropriate due to the use of 10 MV x-rays.

Although changes in dose in the plate implantation build up region due to the presence or absence of the plate were confirmed when 10 MV x-rays are used\textsuperscript{23}, this was within a range that would not have an effect on therapy. If cobalt 60 and other γ-ray sources or 6 MV x-rays are used, it can be conjectured that if the build-up area is shallow, then increased effect on the skin will occur due to the bias towards the irradiated skin side. Thus, special care should be taken when unidirectional irradiation is conducted using x-rays with lower than 10 MV energy.

Thus the effects of metal implants are thought to have a large impact on dose increase than the cranial structure considered in this study.

Conclusions

Changes in radiation dose from use of titanium plate in cranial bone reconstructions were within a range that would not affect postoperative radiation treatment.
References
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