

Monte Carlo-Based Prediction of Internal Dose Distribution for Radiation Conservation Treatment of Cultural Heritage

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1. Introduction

Organic cultural heritage materials such as wood, paper, and textiles are susceptible to biological deterioration caused by fungi, bacteria, and insects, and radiation treatment has attracted attention as a non-contact alternative to conventional chemical methods [1]. For effective treatment, the absorbed dose should be sufficient for biological inactivation without exceeding levels that may damage the materials. However, conventional dosimeters allow dose verification only after irradiation and provide limited information on internal dose distributions. Therefore, this study proposes a Monte Carlo simulation-based method to predict internal dose distributions before radiation conservation treatment and provide baseline data for determining appropriate irradiation conditions.

2. Materials and Methods

A Gaksi mask, one of the traditional Hahoe masks depicting a bride, was selected as the target object. The headdress and facial part are joined by two iron nails, with traces of pigments on the surface and previous repair materials at the joint [2].

The irradiation source was modeled using BEAMnrc based on the MEVEX accelerator at the Korea Atomic Energy Research Institute, with 10 MeV monoenergetic electrons as the incident beam. X-ray CT images of the mask were segmented by density into air, wood, and metal and converted into a voxel-based phantom for dose calculation with DOSXYZnrc. The three-dimensional internal dose distribution under front-face irradiation was then calculated, and depth-dose profiles were analyzed.

3. Results

Figure 1 shows the calculated dose distribution mapped onto the CT cross-sectional images of the Gaksi mask. In the nail-free region, the maximum dose occurred at a depth of approximately 2.1 cm. A local dose increase of about 8% was observed in the wood immediately in front of the metal nail, whereas the dose immediately behind the nail was approximately 30% lower than that in the nail-free region at the same depth. The corresponding depth-dose profiles are presented in

Fig. 2, where the dose decreased rapidly along the path passing through the metal nail, while the wood-only region maintained the expected depth-dose pattern. The mean statistical uncertainty was approximately 0.47% for voxels receiving more than 50% of the maximum dose.

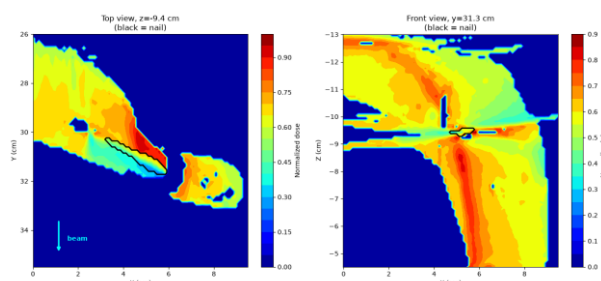


Fig. 1. Calculated dose distributions mapped onto CT cross-sectional images of the Gaksi mask.

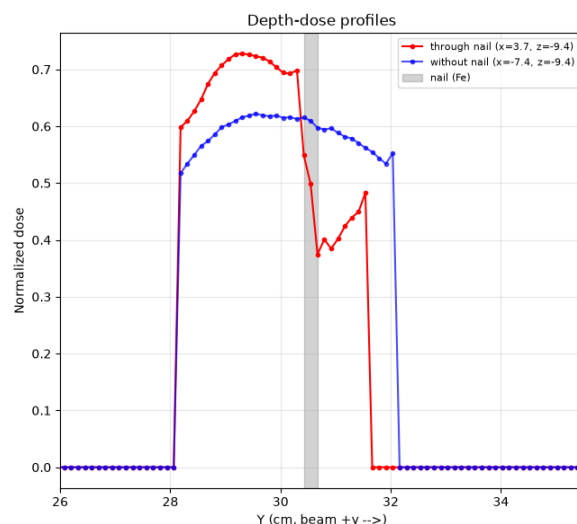


Fig. 2. Depth-dose profiles along paths through and without the metal nail.

Considering the wooden composition of the Gaksi mask, the target dose was selected to provide effective fungal control while remaining within a conservative dose range for wood. Most regions of the mask reached the target dose because of its relatively thin structure, whereas areas shielded by the metal nails received lower

doses and did not reach the target level. This demonstrates the importance of evaluating the internal dose distribution when determining irradiation conditions for radiation conservation treatment.

4. Conclusions

A CT-based Monte Carlo simulation was used to predict the three-dimensional internal dose distribution of the Gaksi mask. The results showed that the metal nail locally altered the dose distribution, increasing the dose in front of the nail and decreasing it behind the nail. These findings suggest that Monte Carlo simulation can be used for pre-irradiation dose prediction and for establishing suitable irradiation conditions, providing baseline information for determining the appropriate absorbed dose in radiation conservation treatment of cultural heritage objects. In future work, the Monte Carlo dose calculation framework will be incorporated into an AI agent-based system to support the automation and optimization of radiation conservation treatment planning.

REFERENCES

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