Water-equivalent Lengths Derived from Proton Computed Tomography

IV. 1. Water-equivalent Lengths Derived from Proton Computed Tomography

Terakawa A.[1], Hosokawa H.[1], Shigihara K.[1], Kajiyama A.[1], Nagao R.[1], Narumi K.[1], Hosokawa H.[1], Fujise Y.[1], Ushijima H.[1], Wakayama Y.[1], Fujiwara M.[2], Hitomi K.[2], Nagano Y.[2], and Nogami M.[2]

[1]Cyclotron and Radioisotope Center, Tohoku University
[2]Department of Quantum Science and Energy Engineering, Tohoku University

High-precise X-ray computed tomography (XCT) has commonly been used to obtain water-equivalent length (WEL) in ion-beam treatment planning because the effect of Compton scattering related to electron density is basically dominant in patients. However, the XCT-based treatment planning provides errors in depth-dose and range simulation due to the photoelectric effect and the beam-hardening effect. Yang et al. have reported that the XCT-based treatment planning causes uncertainties of 2.5 % for lung tissue and 5 % for born tissue in converting Hounsfield unit (HU) into relative stopping power (RSP) with respect to water[1)]. In order to reduce the errors in ion-beam treatment planning, proton computed-tomography (pCT) has recently received attention because pCT potentially provides more accurate RSP data than XCT. In this work, we aimed to derive WEPLs of typical phantoms (ethanol, water, a 40% aqueous solution of potassium dihydrogen phosphate) used in the HU-RSP conversion and various phantoms (resins and aqueous solutions of mineral salts of trace elements in human tissue) from pCT measurements. In addition, we aimed to evaluate and discuss range-simulation errors in proton treatment planning by comparing the WEPLs obtained from pCT with those of XCT.

The pCT measurements were performed using an 80-MeV proton beam and a beam-irradiation system for proton therapy studies[2),3)] at Cyclotron and Radioisotope Center, Tohoku University. Figure 1 shows the experimental setup for pCT. We used polymethyl methacrylate (PMMA) and polyethylene as resin phantoms, and $CaCl_2$, $MgCl_2$ and $FeCl_3$ as aqueous-solution phantoms other than the typical phantoms. Each phantom was a cylindrical one of 3 cm diameter. The proton beam was delivered to the phantom through collimators and a beam-intensity (BI) monitor. The size of the proton beam was approximately 1 mm at the phantom. The residual energy of the proton beam after the phantom was measured with an energy detector in current mode operation while the effect of beam-intensity fluctuation on the energy measurement was corrected using the BI monitor. The BI monitor and energy detector were scintillator detector type using CsI(Tl) equipped with Si-PIN photodiodes. The pCT data were obtained by rotating the phantom at intervals of 3.6^{o}

Figure 2 shows an axial reconstruction slice of the PMMA phantom based on pCT-based WEL values and a filtered-back-projection method. We have found that the deviation of the pCT-based WELs from the theoretical ones were within 3% for those phantoms whereas the deviations of the XCT-based WELs ranged from 1 to 11%. The results of this work have indicated that pCT significantly reduces the uncertainties in range simulation of the conventional ion-beam treatment planning using XCT, and has clinical benefits in taking full advantage of ion-beam therapy.

References

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2) Terakawa A. et al., X-ray Spectrometry, 40 (2011), 198-201.
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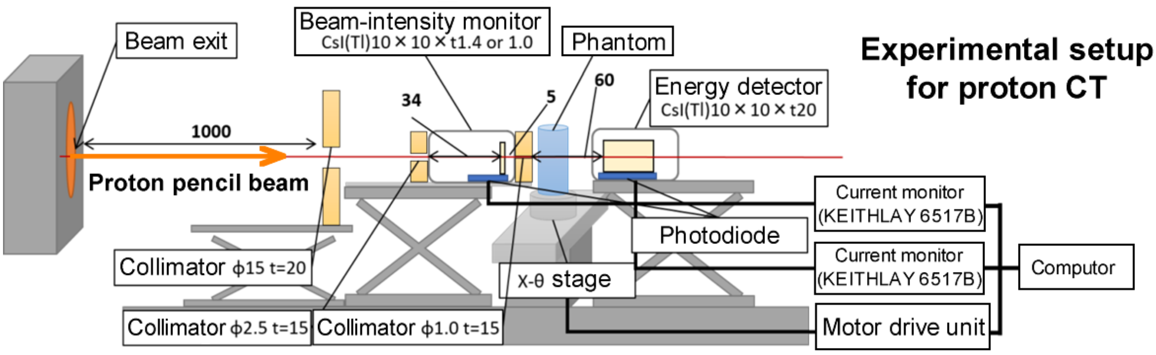

Figure 1. Experimental setup of the proton computed tomography.

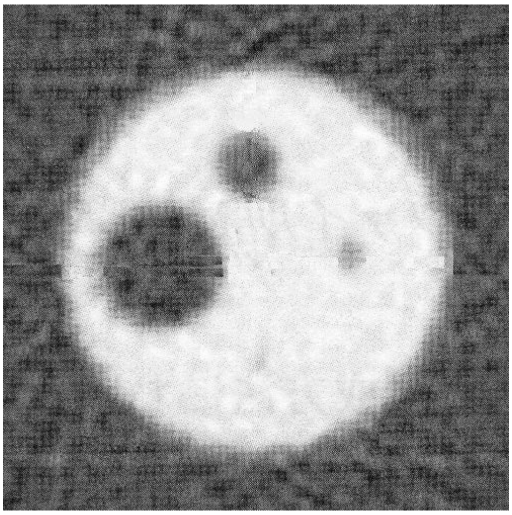

Figure 2. Axial reconstruction image of the PMMA phantom based on pCT-based WEL values and a filtered-back-projection method.