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The study of cancer therapy using Auger electrons induced by monochromatic X-rays and expectation for laser-driven ultra-intense X-ray sources

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This paper describes a proposal of new cancer therapy method using Auger electrons induced by the monochromatic X-rays and future expectation for laboratory-size laser-driven intense X-rays sources.

Conventional broadband X-rays have been widely used as one of the radiation sources for cancer treatment, however when X-rays are irradiated from the outside, most of the dose is absorbed near the body surface and only a small portion is absorbed by cancer cells of inside. This difficulty can be solved by combining monochromatic X-rays with high Z element whose absorption edge is matched to the X-ray photon energy. When an inner shell electron of high Z elements is ionized by X-rays, the generated vacancy is instantaneously occupied by outer electron under the competition of autoionization and the characteristic X-ray radiation. If the Z number is enough high, autoionization process dominates, resulting in the release of Auger electrons. Since the maximum range of electrons is much smaller than that of X-rays, it is possible to locally generate electrons having the effect of killing cells. In cancer therapy, this approach has been pursued as photon activation therapy (PAT).

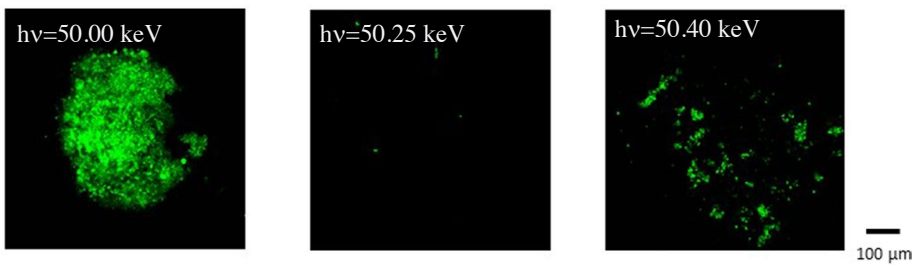
On the other hand, recent advance in Nanotechnology makes it possible for us to produce inorganic nanoparticles with suitable features for biomedical applications. Among these particles, mesoporous silica nanoparticles (MSNs) are promising as a powerful carrier for compounds including high Z elements and can be used to deliver the high Z elements to cancer cells effectively.

Figure shows that the combination of MSNs and monochromatic X-rays has a very strong cancer cell killing effect. In this experiment, Gd atoms were loaded onto the surface of MSNs (Gd-MSN). When Gd-MSNs were added to the tumor spheroids, we observed Gd-MSNs were efficiently taken in and uniformly distributed on the surface and inside of tumor spheroid. Irradiation of monochromatic synchrotron X-rays (SPring-8, BL14B1) at the photon energy of 50.25 keV, which corresponds to the K-shell absorption edge of Gd atoms, resulted in almost complete destruction of tumor. Whereas, at the photon energy of 50 keV, which was slightly lower than the absorption edge, substantial destruction did not occur. This result suggests that the use of precisely tuned monochromatic X-rays opens up the possibility of new type of cancer therapy [1].

In order to establish this new method as a medical technology, it is indispensable to realize high-intensity monochromatic X-ray sources small enough to set in a hospital. In the presentation, we also introduce several candidates of ultra-intense X-rays by use of high peak power lasers [2] and discuss the future expectations of these sources for cancer therapy.

References

[1] Kotaro Matsumoto et al., Scientific Reports, 9, 13275 (2019).
[2] Alexander S. Pirozhkov et al., Scientific Reports 7, 17968 (2017).



X-ray photon energy dependence of the destruction of tumor spheroid with Gd-MSNs. The K-shell absorption edge of Gd is around 50.25 keV. Tumor spheroid was incubated by 50ng Gd-MSNs, and X-ray exposure time was 20 mins. The destruction of tumor spheroid was examined by GFP fluorescence (from ref [1].).