Morphometric imaging of cardiac myxoma by the J-PET scanner combined with Positron Annihilation Lifetime Spectroscopy

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Abstract

Jagiellonian Positron Emission Tomograph (J-PET) is a multi-purpose detector which is used for investigations with positronium atoms in life-sciences as well as for development of medical diagnostics. A prototype of the J-PET based on plastic scintillators was developed at the Jagiellonian University in Krakow, Poland.

Positron Annihilation Lifetime Spectroscopy (PALS) allows examining structure of materials at nano and sub-nanometer level. This technique is based on the lifetime and production intensity of ortho-positronium atoms in free volumes of given structures. It is mostly used for studies of organic materials. J-PET tomograph is capable of imaging of properties of positronium produced inside the human body [1].

The result obtained by the J-PET collaboration with this technique gives a potential to study human body with accuracy not achievable by any other method. The measurement with cardiac myxoma tumor was performed for the very first time.

Positron Annihilation Lifetime Spectroscopy

Positronium is an atom consisting of an electron e^- and its anti–particle positron e^+, its diameter is about 0.2 nm. Therefore it is possible for positronium to be trapped in free spaces between molecules any kind of not conducting matter like cells and tissues (Fig. 1), which are investigated in this study. Since positron can annihilate with an electron not only from Ps, but also with electrons in surrounding matter, mean lifetime value of ortho-positronium trapped in these free volumes can be used to estimate their sizes. This together with intensity of o-Ps production gives us an information about porosity of given material.

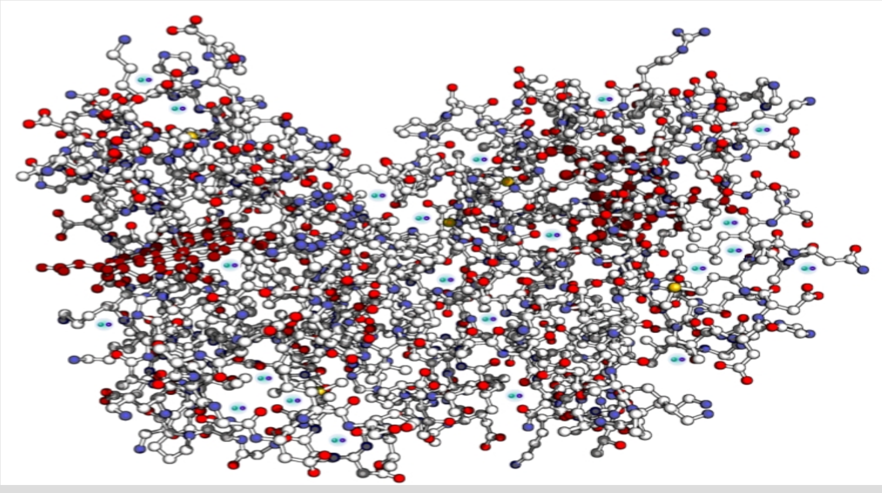


Fig. 1. Exemplary scheme presenting positronium trapping in molecule (hemoglobin).

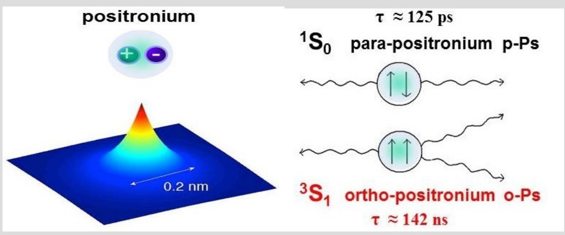
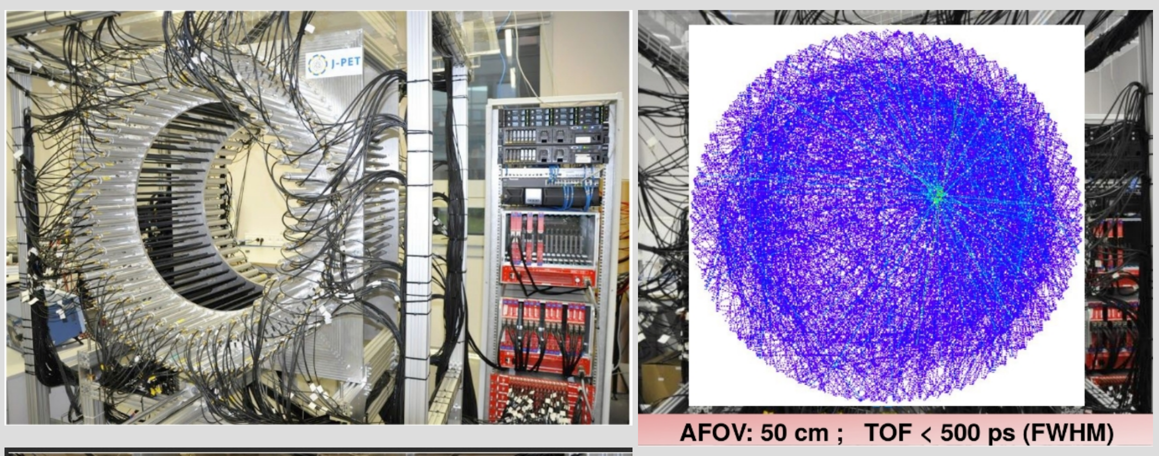


Fig. 2. (left) Positronium atom and the probability of spatial distribution of e^- and e^+ [2]. (right) Decays mode of the two ground states of positronium. (up) Singlet state of anti – parallel spins orientation, p-Ps. (bottom) Triplet state of parallel spin orientation, o-Ps.

Biomedical application of PALS technique

Until recently PALS was not used in biological or medical science. Some newly studies showed it can successfully be applied as a diagnostic technique, enabling to differentiate between cells, tissues and even molecules on accuracy level not achievable before. Due to positronium being trapped in free spaces between molecule and its time being shortened by presence of free radicals and reactive oxygen species it is different for cancer cells or tissues, which produce more ROS than normal cells.

Jagiellonian-PET scanner



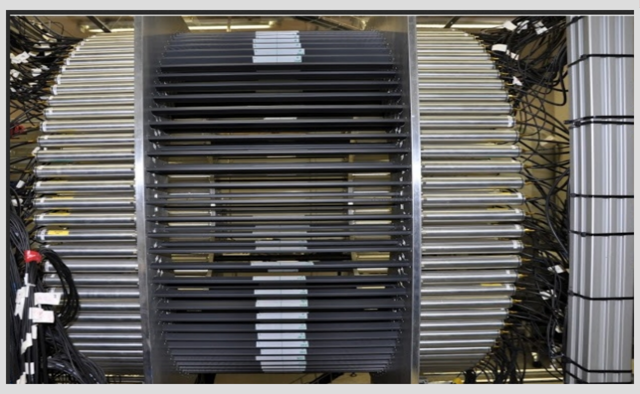


Fig. 3. Photo of J-PET scanner, front and side view. (right) Reconstruction of point-like image in real time [3].

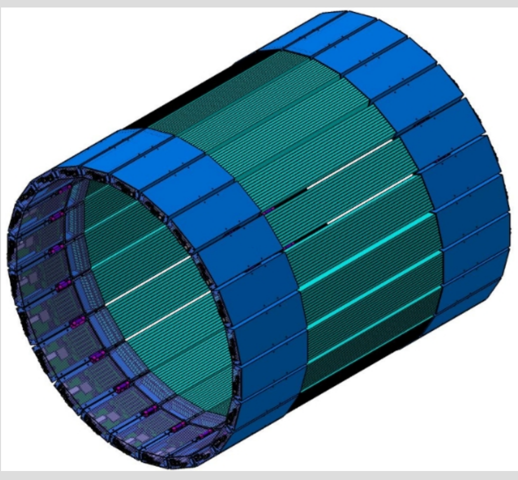


Fig. 4. Scheme of prototype of digital and modular J-PET scanner.

Cardiac myxoma

Cardiac myxoma is very rare heart disease with an overall incidence of about 0.5 per million per year but accounts for approximately 50-75% of benign and about half of the all primary cardiac neoplasms. The tumor usually arises from the endocardium into the cardiac chamber. About 75% of cardiac myxomas are located in the left atrium, and 15-25% in the right atrium. The cells which form the tumor are considered to be remnants of subendocardial vasoformative reserve cells or multipotential primitive mesenchymal cells that persist as embryonal residues during septation of the heart. The precursor mesenchymal cells can differentiate into endothelial and epithelial cells, smooth muscle cells, angioblasts, fibroblasts, cartilage cells, and myoblasts forming myxoma tumor. The only method of treatment of cardiac myxoma is radical surgical tumor excision using extracorporeal circulation.

In case of this study four tumors of this kind fixed in aqueous solution of formaldehyde and one not fixed with mediastinal adipose tissue for comparison were measured. First tumor (I) from 72 years old women was cut into 7 samples 2 mm thick each and second tumor (II) from 61 year old men was measured as one sample, third tumor (III) from 59 year old men was cut into 3 samples and fourth tumor (IV) from 54 year old women was cut into 3 samples. Fifth tumor (V) and adipose tissue from 77 year old men, were measured within 4 hours after surgery, not fixed in formaldehyde. (Fig. 5.)

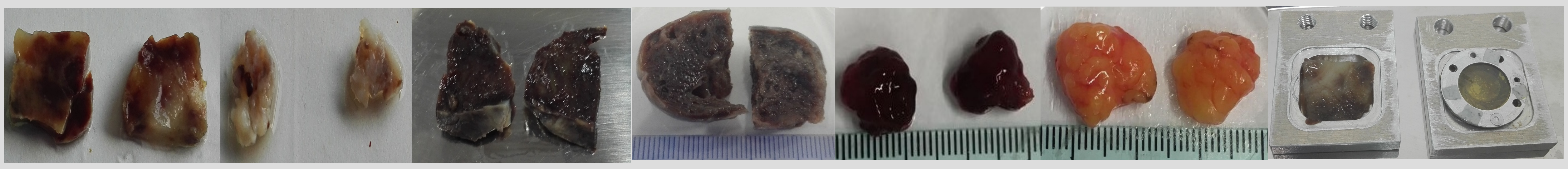
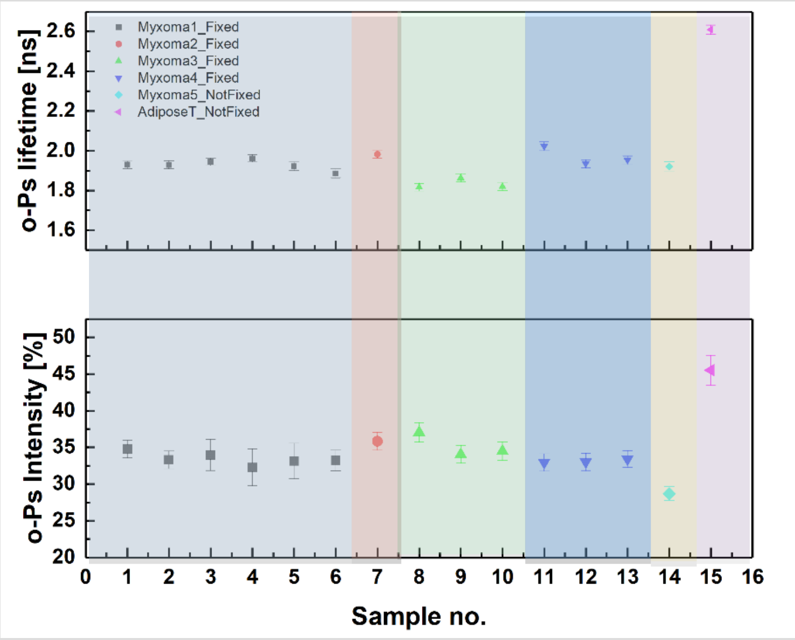


Fig. 5. Exemplary samples of measured cardiac myxoma from left: tumor I, tumor II, tumor III, tumor IV, tumor V (not fixed), adipose tissue (not fixed), measurement chamber.

Results



In the PALS spectra measured for all samples one component related to o-Ps annihilation in the voids was found. Ortho-positronium lifetime and intensity of production are shown in Fig. 6.

Obtained mean o-Ps lifetime value for cardiac myxoma samples was of about **τ = 1.92(11) ns**, which corresponds to the free volumes radii estimated from the Tao-Eldrup model assuming spherical shape of void of about **r = 0.27 nm**. Intensity of o-Ps production is of about **34%**, where for healthy mediastinal adipose tissue o-Ps lifetime was about **τ = 2.61(2) ns**, with intensity of **46%**, estimated free volumes radii of about **r = 0.35 nm.**

Results for all samples from the same tumor are consistent with each other, which means that studied tumors had homogeneous structure on nanometer level. The determined ortho-positronium lifetime differs from the lifetime for water, therefore it proves that this technique can be successfully applied in studies of hydrous biological samples.

Additionally significant difference between cardiac myxoma and adipose tissue proves that this method can be applied with J-PET scanner as better and more effective diagnostic technique.

Fig. 6. o-Ps lifetime and intensity values as a function of sample number. Different colors denoted samples from given tumor or adipose tissue.

Conclusions

Presented results of the first experiments with the cardiac myxoma tumor conducted by the J-PET collaboration proved that PALS technique can be successfully applied for studies of biological samples. Results showed significant differences between tumor and normal tissue. Further studies of normal and cancerous cells, will enable determination of early and advanced stages of carcinogenesis by observing changes in biomechanical parameters employing PALS method combined with J-PET tomography system [1] which is currently being developed at Jagiellonian University [7-12]. These results opens perspective for simultaneous determination of early and advanced stages of carcinogenesis by observing changes in biomechanical parameters between normal and tumor cells and standard PET examination, therefore this techniques combined can be very effective diagnostic tool.

References, Acknowledgment and ethics approval

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