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The Promise of Synchrotron Radiation in Medical Science

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A synchrotron is capable of providing information about structures down to nano, molecular and atomic level. Essentially it accelerates electrons to almost the speed of light, where they have a very high energy level. The electrons are passed through a series of magnets and deflected around a 'storage ring' where they emit beams of extremely intense radiation (light) that can be channeled out of the device. These beams consist of high intensity light across multiple wavelengths and have many useful applications that yield results far superior than conventional medical imaging modalities. For example, synchrotron x-rays are hundreds of thousands of times brighter (more intense) than the x-rays obtained from conventional x-ray machines that are available in labs and hospitals. Synchrotron measurements enable characterization across scales, ranging from life-size images down to nano, molecular and atomic structures due to its high resolution and high signal-to-noise ratio. The applications of synchrotron radiation in medicine are many and varied. Diagnostic imaging, the major medical application of x-rays, represents just one application of synchrotron radiation. In this editorial, I briefly summarise the applications of synchrotron radiation in medical research and provide a few examples of their impact in medicine.

After first application of synchrotron light in 1956, synchrotron radiation has contributed significantly to the physics and chemistry of condensed matter as well as to material science and medicine. Although the use of synchrotron radiation in the field of medicine is not as widespread as that in physics and chemistry, its applications are increasing in recent years (1). The number of synchrotron light sources exceeds 75 worldwide and the number of users is of the order of 20,000 per year. Synchrotron light source was installed in Melbourne, Australia in 2007 (www.synchrotron.vic.gov.au), thus, Australian researchers from different disciplines will now benefit from the local availability of this technology. I will focus on the field of medicine.

Cardiovascular disease imaging: Cardiovascular disease is the leading cause of death in the developed world. Therefore, a great deal of interest is to use an imaging modality that could identify abnormalities such as coronary artery plaques or stenoses at any early stage before they lead to myocardial infarction. Currently, the standard reference for imaging the coronary arteries is invasive coronary angiography owing to its high spatial and temporal resolution. However, it is not only an invasive procedure but associated with procedure-related complications. Invasive coronary angiography has been challenged by the less invasive imaging modalities, such as multislice computed tomography angiography and magnetic resonance angiography, which were reported to be promising alternatives to conventional angiography. Despite their diagnostic accuracy in coronary artery disease, computed tomography and magnetic resonance imaging are of limited value in differentiating or characterizing coronary plaque components.

Coronary angiography is an important clinical application of synchrotron radiation. Both coronary artery branches and coronary stents can be evaluated with synchrotron imaging with potential value reported in the follow-up of patients at high risk of developing in-stent restenosis, since it is more accurate for the analysis of stented segments than other less invasive techniques and uses small radiation doses (2). Synchrotron-based phase-contrast X-ray computed tomography imaging of atherosclerotic plaques is another example demonstrating its advantage over conventional imaging for quantitative investigation of plaque components and detection of unstable plaques (3). Shinohara et al in their study first demonstrated that phase-contrast CT imaging is far superior to conventional computed tomography imaging as synchrotron radiation can estimate the tissue mass density of atherosclerotic plaques and detect lipid-rich areas, while conventional computed tomography is not highly sensitive to detect non-calcified soft plaque components. The application of phase-contrast X-ray imaging in cardiovascular disease is very promising, although further studies are required to confirm its value before it is recommended to clinical practice.

Breast cancer imaging: Breast cancer is the highest cause of cancer-related deaths among Australian women. Although mammography is the standard technique for screening and diagnosing breast cancer, it has limitations to detect calcification present in the breast tissue which may suggest breast cancer. Conventional computed tomography scanners do not have sufficient spatial resolution to localize the tumour and reveal its size and inner content or structure and also are disadvantaged by the high radiation dose. Synchrotron-based diffraction enhanced imaging (DEI) offers high resolution computed tomography (CT) images of the breast tumours and shows promise in the detection of early tumours, with reduced radiation dose. Bravin et al in their recent study reported that high resolution DEI-CT images provide strong contrast and allow visualization of details invisible in conventional radiographs (4). Their results suggest that synchrotron DEI images significantly improved visualization of the morphology and overall architecture of the breast tissues, with details smaller than 0.1 mm available for analysis.

Bone disease imaging: Osteoporosis is a common metabolic disease which leads to an increased risk of fracture in elderly population. Bone density measurement is routinely used to detect the osteoporosis, however, recent data suggested that bone mineral density alone does not explain or predict bone health. Mineral concentration and distribution of elements, such as calcium and phosphorus are considered to have the same degree of importance. The development of X-ray fluorescence imaging technique that utilizes synchrotron radiation has recently been reported to be valuable in the evaluation of elements distributions in bone zones and helpful for understanding functions in those structures (5). Other applications of synchrotron microtomography include 3D display of microarchitecture of the bone cortex and trabecular thickness in normal and disease bones, which allows characterization the difference in bone quality between different pathological situations.

Radiotherapy: The great majority of tumours are nowadays treated by surgery and/or by treatments including adjuvant chemotherapy and radiotherapy. With regard to standard medical radiation therapy, it generally involves high-energy photons with aim of treating deep-seated tumours due to its high penetration in matter. However, this technique does not necessarily produce optimal biological effects as it is associated with the deleterious effect on surrounding normal tissues. Synchrotron radiation has opened a new path in innovative radiotherapy strategies (6). The inherent high collimation indicates that it can be targeted with great accuracy onto small tumours with the beam energy be optimized for a particular path, while the associated dose to surrounding tissue is minimal. A considerable amount of data involving anti-cancer strategies using synchrotron radiation prompted researchers to evaluate their potential clinical transfer by carefully taking into account their radiobiological features. Further reports are expected in this area with increasing role of synchrotron radiation in tumour radiotherapy.

The application of synchrotron radiation in medicine is rapidly expanding and exciting. The number of synchrotron machines is increasing worldwide with more under construction. While many of these facilities have medical research programmes, only a small number of medical researchers are aware of the opportunities available from synchrotron radiation as its application is mainly dominated by physicists and chemists. In addition to the applications listed above, there are many applications of synchrotron radiation in other medical areas. Although most of the applications are still being studied at the experimental level, synchrotron radiation has made a major contribution to medical research by improving our understanding of various pathologies.

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