# Nuclear Medicine: The 21$^{st}$ Century Breakthrough

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Every few decades, a great medical discovery revolutionizes the world. In the 18$^{th}$ century, the discovery of the vaccination led to the worldwide eradication of smallpox, saving billions. In the late 19$^{th}$ century, germ theory, the notion that microorganisms are the causes of specific diseases, supplanted the previous misconceptions, saving billions more with derived practices such as pasteurization and the improvement of public sanitation. Most recently, the important medical discoveries and breakthroughs of the 20$^{th}$ and 21$^{st}$ centuries, and perhaps of all time, stem from nuclear technology and science. It is impossible to overstate the impact that nuclear science and technology has made on both diagnosis and treatment of disease, spanning from blood cell disorders to cancer.

Nuclear medicine is a unique medical discipline that uses radiopharmaceuticals to non-invasively study, diagnose, and treat diseases (*Advancing nuclear medicine*, 2007). A radiopharmaceutical is a radioactive chemical substance used in medicine, and can be a radionuclide, an element that is radioactive and that emits energy, or it can be attached to a carrier molecule (*Advancing nuclear medicine*, 2007). This carrier molecule can be drugs, proteins, or a variety of other particles. Radionuclide imaging is instrumental in detecting and diagnosing diseases because nuclear medical diagnostics offer detailed pictures both at the molecular and cellular levels.

Nuclear imaging allows physicians to obtain vital physiological information about their patients without highly invasive and damaging techniques, such as surgery or biopsy. In the past, it had been impossible to obtain a detailed picture of the inside of a human body, an insight necessary to help treat human ailment. Radiopharmaceuticals known as tracers emit energy in the form of gamma rays, a type of electromagnetic radiation, and are administered to individuals by ingestion, inhalation, or intravenous injection. The most common tracer is technetium-99 (Britton, 1995). Approximately 85% of nuclear diagnostics use technetium-99, with some 30 million procedures being conducted each year ("Radioisotopes," 2012).

Conditions are diagnosed in radionuclide imaging when, in a nuclear medical scan, an imaging instrument such as a gamma camera or Geiger meter detects gamma radiation and constructs three-dimensional images that show biochemical changes (*Advancing nuclear medicine*, 2007). Some common examples of tracers used in nuclear diagnostic imaging include the Carbon-11 and Nitrogen-13 isotopes (*Advancing nuclear medicine*, 2007). A common practice in radionuclide detection involves replacing a stable carbon atom of a glucose molecule with a radioactive one, synthesizing the glucose molecule as a tracer. The replaced carbon atom exhibits the same chemical properties of a non-radioactive carbon atom, other than the negligible radiation, and, thus, is very safe to ingest. This technique, for example, is especially useful to monitor the digestion of food ("The world," 2000). Radionuclide imaging provides quantitative data about tissue, disease conditions, and bodily processes, instead of just providing information about anatomy, and, so, the radionuclide form of detection is far superior to conventional radiography, such as ultrasound, CT and MRI, with some diseases being able to be detected months earlier. For example, breast and prostate cancers have been found to be detectable approximately six months earlier when using radionuclide imaging than using conventional radiographs (Britton, 1995). Because they determine disease based on molecular and biological changes rather than anatomical ones, radiopharmaceuticals can "identify the existence and location of cancer cells long before they are visible using traditional imaging methods" (*Advancing nuclear medicine*, 2007).

Two leading techniques of nuclear medical diagnostic tools involve the use of positron emission tomography (PET) and single-photon emission computed tomography (SPECT). Both of these techniques involve the detection of gamma radiation from radiopharmaceuticals ingested and show functions like blood flow and glucose metabolism of the brain. In PET, common radionuclides include Carbon-11, Fluorine-18, and Nitrogen-13, all of which have decay times of no more than an hour (Freudenrich, 2000). The use of radioisotopes that have short decay times, or half-lives, is characteristic of PET, so PET centers usually have to be located near particle accelerator devices, where these isotopes are made (Freudenrich, 2000).

The use of SPECT, comparatively, is more widespread, cost-effective, and practical because radioactive substances with longer half-lives are used. Another important distinction between PET and SPECT is that SPECT imaging uses tracers that emit gamma radiation directly, while PET imaging uses tracers that emit positrons, which lead to the production of two gamma photons. And although the images produced are less detailed than the images produced from PET, due to the double gamma photon production, SPECT imaging is less expensive and more accessible, because medical centers that engage in SPECT imaging do not have to be located near a particle accelerator (Freudenrich, 2000).

One example of nuclear medical imaging that has been proven to be successful is cardiovascular imaging, an example of which being the stress thallium test. In this test, a patient is injected with radioactive thallium before exercising on a treadmill. After, the patient is imaged with a gamma ray camera–that captures the radiation, and, over multiple trials, images are compared to reveal information about blood flow. These sorts of techniques have proved to be instrumental in detecting blocked arteries and arterioles in the heart (Freudenrich, 2000).

Traditional methods of radiation diagnosis include imaging procedures that involve the use of X-rays, computed tomography (CT), and magnetic resonance imaging (MRI) solely provide images of physical human structures rather than chemical and biological processes. These methods are not as useful as their nuclear counterparts, but in recent years, newer methods fuse the traditional methods with nuclear methods. Nuclear medicine has grown so rapidly due to advances in technology, and this has led to the hybrid SPECT/PT and PET/CT. The PET/CT and SPECT/CT methods of diagnostics are techniques that combine the anatomical imaging capabilities of traditional radiology with physiological imaging capabilities of nuclear diagnosis that provides information of living cells, organs, and bio-molecules of the body (“Millions benefit from,” 2011).

These new imaging techniques allow for better diagnosis rates up to 30% than with the solely nuclear approach, and these are very powerful tools that can provide substantive information about both anatomy and physiology about diseases like dementia and cancer (“Radioisotopes,” 2012) Due to the desirability and effectiveness of radionuclide imaging, from 1999 to 2005, nuclear medicine procedures have grown from 7 million to over 11 million, and will continue to grow as these new techniques are further developed (Delbeke & Segall, 2011).

Even though 90% of nuclear medical procedures are for diagnosis, nuclear technology has been instrumental in the treatment of some of the world’s deadliest medical conditions, such as blood imbalances, bone pain, and certain types of cancers (“What is nuclear,” 2013). Each year, over 15 million Americans undergo nuclear medical treatments that help them battle cardiovascular, neurological, other physiological diseases, and more. For example, radioiodine, or I-131, has been used extensively to treat Graves’ Disease, a type of thyroid disease (“Millions benefit from,” 2011). Because rapidly multiplying cells is characteristic of most forms of cancer, radiation therapy has been used to try to kill these cancerous cells. Traditional radiation therapy uses “ionizing radiation to kill cancer cells and shrink tumors by damaging the cells’ DNA, thereby stopping these cells from continuing to grow and divide.”

Unavoidably, adjacent cells are killed in the process as well, which is why many people who undergo this traditional treatment suffer from hair loss. However, if tracers such as the phosphorus-32 isotope are inserted into the bloodstream, tumors can be more precisely identified. Targeted radionuclide therapy is a very systemic treatment, unlike traditional external radiation therapy. Moreover, targeted radionuclide therapy uses beta particles, alpha particles, and Auger electrons to attack cancer cells with great specificity. This method eliminates both a primary tumor site and the cancer that has spread throughout the body by releasing energy from the radionuclide without as much damage to adjacent cells (*Advancing nuclear medicine*, 2007). This is something that is very difficult for traditional external radiation therapy. Studies have shown that alpha-emitting radionuclide treatment of cancer has greater biological effectiveness than conventional external beam radiation, since radiopharmaceuticals can be designed to be attracted to specific organs, bones, or tissues (*Advancing nuclear medicine*, 2007). For example, radioactive iodine-131 is used to treat cancers affecting the thyroid gland, and this radioactive iodine treatment is so successful that it has completely usurped traditional treatment methods and has virtually replaced thyroid surgery (“Nuclear medicine,” 2000).

Despite the vast advantages and benefits of nuclear medicine, there have been concerns about the risks of low levels of radiation exposure, both to patients and the individuals around them. But, the level of radiation apparent in radionuclide imaging is often “less than, or comparable to, equivalent X-ray procedures,” and have been declared a negligible radiation risk by the International Commission on Radiological Protection (Britton, 1995). According to the Administration of Radioactive Substances Committee, the radiation from any procedure has to be in concordance with the ALARP principle, or “as low as reasonably practical.”

Improvements to nuclear technology in medicine over the last fifty years have been extensive. Although nuclear medicine has already revolutionized the diagnosis and treatment of many diseases, its full potential is only now being realized, with recent nuclear medical approaches being applied to neuroscience, drug development, and preventive healthcare. As researchers continue to apply nuclear science and technology to medicine, further development in this field will undoubtedly unlock new secrets about the human body, detection and treatment of human ailment, and save more lives than all previous medical breakthroughs have in the past combined.

References

*Advancing nuclear medicine through innovation*. (2007). Washington, DC: The National Academies Press. Retrieved from http://www.nap.edu/catalog.php?record_id=11985

Britton. (1995) Nuclear medicine, state of the art and science. *Radiography.*

Delbeke., & Segall, (2011). Status of and trends in nuclear medicine in the united states. *The Journal of Nuclear Medicine*, *52*(10), doi: 10.2967/jnumed.110.085688

Freudenrich. (18, October 2000). *How nuclear medicine works*. Retrieved from http://science.howstuffworks.com/nuclear-medicine.htm

*Millions benefit from advances in nuclear medicine*. (2011, January 25). Retrieved from http://www.nuclearscienceweek.org/news/detail/millions-benefit-from-advances-in-nuclear-medicine/

*Nuclear medicine: radioisotopes for diagnosis and treatment*. (2000). Retrieved from http://www.lbl.gov/abc/wallchart/chapters/13/2.html

*Radioisotopes in medicine*. (2012). Retrieved from http://www.world-nuclear.org/info/inf55.html

*The world of nuclear science.* (2000). Retrieved from http://library.thinkquest.org/C004606/applications/medicine.shtml

*What is nuclear medicine?*. (2013). Retrieved from http://interactive.snm.org/docs/whatisnucmed.pdf