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Nuclear imaging - an evolutionary shift in diagnostic radiology

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Abstract

Nuclear imaging (NI) is a new approach in the field of radiology which plays a vital role in the early diagnosis of disease in the recent decades. Although in the present time’s conventional radiographs are being routinely used for diagnosis in dentistry, NI has been in use only for certain oral and maxillofacial pathologies. NI relies on metabolic and physiological processes of tissues and help in accurate diagnosis. Even though NI is not used on daily basis in the field of dentistry, the dental professional must have a basic knowledge on its applications. This review is an attempt to provide a basic insight into nuclear imaging in the oral and maxillofacial region.

Keywords: Nuclear imaging, PET scan, Radioisotope, SPECT.

Introduction

Nuclear imaging (NI) also known as radionuclide imaging, has been defined as incorporating all applications of radioactive materials in the diagnosis or treatment of the disease, and in medical research.[1] NI is a noninvasive technique, which provides information on pathophysiological and pathobiochemical processes. This speciality of medicine uses radioactive tracers that emit gamma rays. It holds a lot of promise in all diagnostic areas in the field of medicine and dentistry. However, it’s relatively poorly understood and less utilized in oral and maxillofacial pathologies. Hence an increased awareness regarding the applications of NI in diagnostic as well as therapeutics is needed for dental professionals. This review is an attempt to provide a basic insight into nuclear imaging.

History

The scientific understanding of radioactivity and its advantages goes back to the Roentgen (1895) and Becquerel's ground breaking work (1896), further studies by M.Curie (1898) and Rutherford (1911) has shown that heavy elements including uranium, thorium and radium demonstrate radioactivity.[2]The name isotope was first suggested by Soddy in 1913.The radioactive decay law was also proposed by Soddy.[2] Radioisotopes are used in medicine because they decay quickly and are suitable for diagnosis and therapy due to their shorter half-life. In the 1920s, radioactive phosphorous was used in animals to show metabolic process in an intact animal- the bone scan. Later phosphorous -32 was used to treat a patient with leukemia. [2] Radioactive iodine was used to study thyroid physiology in the late 1930s and is now still being used today for therapy and imaging. In 1939 Strontium-89 was first tested. [2] With the discovery of technetium-99m in 1939 by Italian Emilio Serge and American Glenn Seaborg there was a major breakthrough in nuclear medicine. [2]

Radio Isotopes

Elements that have a same atomic number but differ in their atomic masses are radioisotopes; therefore contain a same number of protons but different number of neutrons. These unstable elements undergo decay and emit energy as alpha(α), beta(β), beta plus(positron) and gamma-rays and are thus referred to as radioisotopes.[3] These radioisotopes with proper safety and appropriate performance in clinical use, and approved by FDA, when used in healthcare system are referred to as radiopharmaceuticals. Technetium-99m, iodine-123, iodine-131, gallium-67 and thallium-201 are the most foremost common radionuclides utilized in the liquid form whereas xenon-133, krypton-81m, technetium- 99m and diethylene-triamine-pentaacetate (DTPA) are the foremost commonly used gaseous/aerosol forms. [4]

For maxillofacial pathologies the following radionuclides are most widely used Technetium-99m: Tumors of salivary glands

Gallium-67: Detection of osteomyelitis in the jaws.

18F Fluorodeoxyglucose (FDG): Malignant tumors in the maxillofacial region.

Nuclear imaging techniques include:

Salivary gland scintigraphy:

The latin word "Scint" refers to "spark". Scintigraphy is technique where-in radioisotope is taken internally, and the resultant emitted characteristic radiation is captured by gamma cameras to produce two-dimensional image. [5]

Technetium-99m- Methylene Diphosphonate (Tc-99m-MDP) which has affinity for calcium-rich hydroxyapatite crystals of bone undergoes 'chemisorption', is used to attain the bone metabolic activity (Kalayci et al.2010). [6]Tc-99m-MDP tends to accumulate in areas of active or high bone turnover, based on the degree of osteoblastic activity and presence of vascularisation (Kalayci et al.2010).[6] The areas of increased uptake of radioisotope appear as so called "hot spot" and those with decreased or no uptake will be called as "cold spot" (Ferreira et al. 2002). [5]

Benign, malignant bone tumors and metastatic lesions of bone demonstrate increased uptake of technetium 99. Lung, breast, prostate, thyroid, and kidney are the most sites of metastatic bone lesions.[5] Fibrous dysplasia and Paget's disease also show improved uptake on the scan.[6,7] Active periodontal disease also shows an increased uptake of the radiopharmaceutical in the alveolar processes of the mandible and maxilla. [5]

Areas of decreased uptake lesions are commonly observed in lesions resulting from radiation treatment, local vascular compromise, early osteomyelitis, multiple myeloma, and avascular necrosis. Wharthin's tumor and oncocytomas demonstrate increased uptake and decreased washout time. Increased uptake and increased washout are usually shown by acute inflammation of the glands, whereas chronic inflammation shows decreased uptake. Others include aplasia or agenesis of the gland, obstructive disorders, traumatic lesions, fistulas. [8, 9, 10]

Lymph node scintigraphy

Lymphoscintigraphy is used in the treatment and staging of breast cancer, malignant melanoma, oral and head/neck malignancy, especially OSCCA. Technetium 99m sulfur-colloid is injected in four to six subcutaneous sites around the neoplastic lesion which will be carried away in the lymphatic channels to the sentinel node. The pattern of lymphatic spread and therefore the sentinel node can then be imaged employing a gamma camera. The sentinel node is then evaluated for any metastasis. [11]

Positron emission tomography (PET)

It is a functional imaging technique that uses positron emitting radiotracers for early diagnosis, tumor and nodal staging, monitoring the prognosis of disease therapy, to assess the chances of recurrence in cancer. (Townsend 2004, Kubicek et al.2010). The basic principle of PET is to detect the positron which is emitted by radioisotopes that are injected into the body using gamma cameras; later the tomographic images are generated using a computer. [12, 13]

The frequently used radiotracer in PET scanning is fluorodeoxyglucose (FDG), which is an analogue of glucose that is labelled with fluorine-18(Townsend 2004) which has a longer half-life (110 minutes) thereby allowing more transport time to the effected sites. [13]

FDG is taken up by metabolically active tumour cells. The rate of uptake of FDG by the tumour cells is directly proportional to their metabolic activity because malignant cells tend to have more glucose utilization, increased regulation of hexokinase activity and increased metabolic activity when compared to adjacent normal cells (Kapoor et al.2004). Hence FDG-PET measures cellular glycolysis, reflecting the proliferation and abnormal growth of the affected cells (Kapoor et al.2004). [15]

PET plays a very pivotal role in early detection of the head and neck cancers and above all it can also locate the occult primary malignant tumours that undergo distant metastasis and manifest in the body as secondary tumours elsewhere.[16] FDG-PET also helps in evaluating increased blood flow activity in grafts and in the regions of osteosynthesis, indicating bone repair in the graft (Boloor et al. 2013).[17]

PET scans are useful in oral squamous cell carcinoma (OSCCA) where OSCCA is detected at a stage when there are no palpable nodes in the neck. [17]

False positive results are may also be seen in PET scan due to accumulation and uptake of the radiotracer in non-neoplastic tissue like new granulation tissue, inflammatory lesions, tuberculosis and sarcoidosis. Recent irradiation treatment in the OSCCA neck would also give false positive results. [18]

Single Photon Emission Computed Tomography (SPECT)

SPECT uses single photon gamma-ray emission as the source for image formation. SPECT differs from PET in that gamma radiation is emitted and measured directly by the gamma cameras where as in PET positrons are emitted from the radiotracer which annihilate with electrons to release of two photons in the opposite direction which are then detected by gamma cameras to produce a three dimensional tomographic image.[19]

SPECT is useful in determining asymmetrical mandibular condylar hyperplasias.[20] An increased uptake of 99mTC-methylene diphosphonate in maxillary bones is seen in few patients who are treated with biophosphonates suggesting probable osteonecrosis of the jaw.[21] SPECT also plays a very vital role in implant dentistry, where the peri implant osteoblastic activity and osseous integration process can be assessed in immediate loading implants.[22]

Nuclear Imaging in Tissue Engineering

PET scan is also used to evaluate the osteogenic metabolism of the genetically engineered bone marrow-derived mesenchymal stem cells for repairing of critical-size bone defects. In molecular imaging, in vivo PET shows an increase of matrix metalloproteinase and CT gives an idea about bone formation changes at various stages after bone morphogenetic protein (BMP)-induced cell injection. [23]

Nuclear Imaging of TMJ

Early changes in the TMJ can be diagnosed using scintigraphy which helps in prevention of further joint disc abnormalities. Radionuclide 99mTc is commonly used for the examination. SPECT is also an ideal technique of imaging as its sensitivity is high however, its specificity is low. Increased uptake of the radioisotope can be seen in inflammation, trauma, or tumors.[24]

Nuclear imaging in forensic odontology

Establishing the age at death of individuals is an important step in forensic identification. The amount of radiocarbon present in tooth enamel as a result of nuclear testing is a remarkably accurate indicator of when a person was born. Age is determined to within 1.6 years, whereas the commonly used morphological evaluation of skeletal remains and tooth wear is sensitive to within 5 to 10 years in adults. Dental enamel does not remodel and thus captures dietary radiocarbon values at the time of juvenile formation. Most other human tissues do remodel but at differing rates and therefore collectively offer key information relative to the estimation of the death date.[25]

Advantages of Nuclear imaging [26]

1. It can help in early diagnosis of the disease and evaluate the outcome during the initial post treatment phase.
2. NM helps in detecting metastatic activity.
3. Number of exposures are less for examining different anatomical locations of single/multiple lesions
4. Provides clear anatomical details of lesion with high resolution
5. Provides functional images of pathophysiological and pathobiochemical processes of tissues and organs.

Disadvantages of nuclear imaging [24]

1. Spatial resolution is slightly poor compared with radiographs, CT or MRI.
2. Expensive
3. Exposure to ionization radiation
4. Rarely adverse reactions like allergies to radiopharmaceuticals which are
5. Injected into the body

Conclusion

Nuclear imaging is an emerging non-invasive technique in dentistry for detecting various diseases processes; it includes techniques which are sensitive and highly specific for imaging inflammation, infection, and malignancies. In the new modern era, evolution of these hybrid imaging techniques made a major progress in diagnostic radiology and has thus become a standard clinical imaging modality in the field of medicine and dentistry. Since nuclear diagnostic techniques are being commonly used in dental practice now a day, it is important for the dental professionals to be familiar with all the necessary information and knowledge regarding these imaging techniques. Early diagnosis of the disease using these recent novel approaches in radiology prevents disease complications in near future owing to the fact that "*Prevention is better than cure*".

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