Advanced Imaging Techniques

Among the most important methods of diagnosis and treatment planning for diseases, are radiological diagnosis methods. In addition to the clinical examination, radiological examination will provide the physician with information about the boundaries, size and relationship of the pathological lesions with adjacent tissues. The information obtained will also guide treatment planning.

Conventional radiologic methods are sometimes inadequate in diagnosis and may cause errors. For this reason, in addition to the use of conventional radiologic diagnostic tools in the field of dentistry, new diagnostic tools, which have made great progress with the advancement of technology in recent years, have also started to be used.

Since 1896, when radiography first started to be used in dentistry, efforts have been ongoing to improve the quality of X-ray formation, to understand the harms of ionizing radiation, and to try to reduce them. In the early periods when dental radiographs were first used, the radiographic image was formed in the form of film in both intraoral and extraoral applications. During this time, advances in X-ray film technology have increased the sensitivity of the film, reduced the formation of artifacts, and shortened the image acquisition time.

With the development of computer technology in the early 1940s, the first steps of digital imaging in radiologic diagnostic devices began to emerge. In the first stages of digital radiographic imaging, film-based sensors were scanned in a computer environment, and images were obtained. This two-stage application is defined as **indirect digital radiographic imaging**. In the 1960s, the development of electronic image receivers enabled the development of **direct digital radiographic imaging** and **computer-aided diagnostic methods (Computed Tomography).**

II- GENERAL INFORMATION

A- COMPUTERIZED TOMOGRAPHY (CT):

The principle of radiologic imaging methods is based on obtaining a two-dimensional image of a three-dimensional object. In CT imaging, lesions or tissues with high density obscure those with low density. Tomography is a technique that allows selective visualization of anatomical structures or lesions at the desired depth. The essence of the imaging technique is based on obtaining cross-sectional radiographs by moving the tube and film holder in opposite directions during acquisition.

Conventional radiologic methods may cause inaccuracies in showing the real boundaries of lesions and soft tissue relations. Especially in the head and neck region, the relationships and borders of lesions with neighboring anatomical structures may not be determined accurately due to various superpositions. In recent years, some innovations have been found in tomographic imaging. The most important of these is computed tomography (Figure-1). The CT technique is based on computer-assisted imaging of the radiation absorption level of various body tissues.

Figure 1: Computed tomography device.

Studies on computed tomography were carried out in the 1960s by the American Professor of Physics A. M. Cormak, but the first design and use of computed tomography was carried out by the British Physicist Dr. G. N. Hounsfield in 1972. With this technique, Hounsfield obtained images of the head in various planes using a narrow collimated, moving X-ray beam (Figure-11). The analog signals resulting from the radiation emitted from this beam are digitized by a computer, and the data formed by analyzing mathematical algorithms is formatted to form the axial tomographic image. The images obtained with this technique are superior to those obtained with other conventional techniques. Since 1972, computed tomography has been described under different names, such as computed axial tomography, computed reconstruction tomography, computed tomographic imaging, and axial tomography.

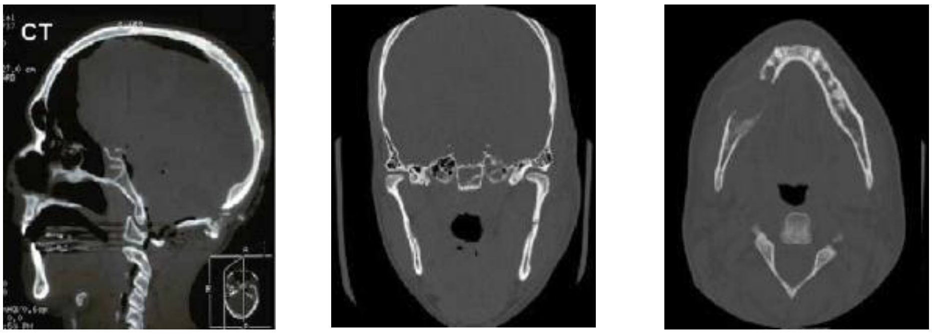


Figure 2: Ct images of the head in sagittal, coronal and axial planes.

In its simplest form, computed tomography is based on well-collimated X-ray beams emitted from a tube and directed into bright detectors or ionization chambers. Depending on the geometric shape of the scanner, the radiographic tube and detectors move synchronously on an axis around the patient, or the beam source moves in a circular motion within the annular detectors. This movement of the scanner enables continuous and serial image acquisition. The scanners most commonly used today move in a helical or spiral pattern to provide images. In computed tomography, a thin beam of X-rays is sent to the patient while the table on which the patient is lying is in a fixed position, and a cross-sectional image is obtained. If a new section is desired, the table is moved forward by the desired amount, and a new section is obtained. **Spiral computed tomography** is a new technique that can be applied with the development of tubes that can produce X-rays for longer periods of time without interruption as a result of technological developments in recent years. In spiral CT, while the tube produces X-rays continuously for 20–80 seconds, the table on which the patient is placed is advanced in the CT device at the desired speed. As a result, instead of a single slice, a block as thick as the table is moving is examined. Since the shape of the block resembles a spiral, the method is called **"spiral"** or **"helical"** (Figure 3). In this type of scanner, the patient lies on a stretcher with a rail around which the X-ray source and scanners rotate, and the stretcher moves at a constant speed into the tube. Compared to the growing number of scanner types, spiral scanners stand out because they produce multiplanar images, have a shorter procedure time (12 seconds to 5 minutes), and expose the patient to less radiation (75% less). With spiral CT, the examination can be completed in as little time as, for example, a breath-hold. This largely prevents deterioration in the quality of the examination due to involuntary movements in young children or in patients with confusion. In addition, perhaps a more important advantage is the so-called dynamic CT, which allows the organ or vessel staining to be performed at the optimal time after rapid intravenous administration of the contrast medium. In this way, the chance of detecting diseases that cannot be detected by conventional CT increases, and the vessels can be visualized with the method known as **CT-angiography** as a result of examining the vessels during the period when the vessels are most stained (Figure 4).

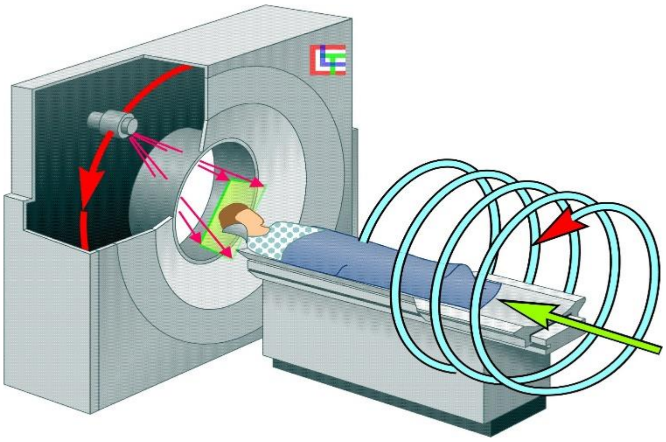


Figure 3: Spiral (helical) tomography (15).

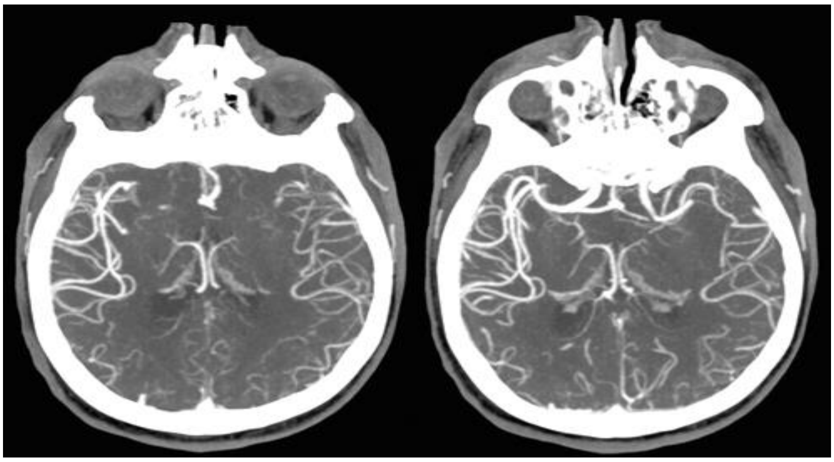


Figure 4: CT-angiography

A computed tomography image is a digital image that is formed by combining a large number of impressions sent to a computer. For example, if a slice is acquired at one-third of a degree, 1080 slices mean that the patient rotates 360 degrees around the patient. The data from 1080 slices provides enough information to reconstruct a single image.

Computed tomography has several advantages over conventional imaging techniques. First, the superposition of areas outside the region of interest on the image is avoided. The second advantage is its high resolution, which allows it to show differences between tissues with contrast changes of less than 1%. In conventional radiography techniques, this rate is 10%. The third advantage is the ability to examine axial, coronal, and sagittal planes (Figure 5) in a single image. This is called **multiplanar imaging**.

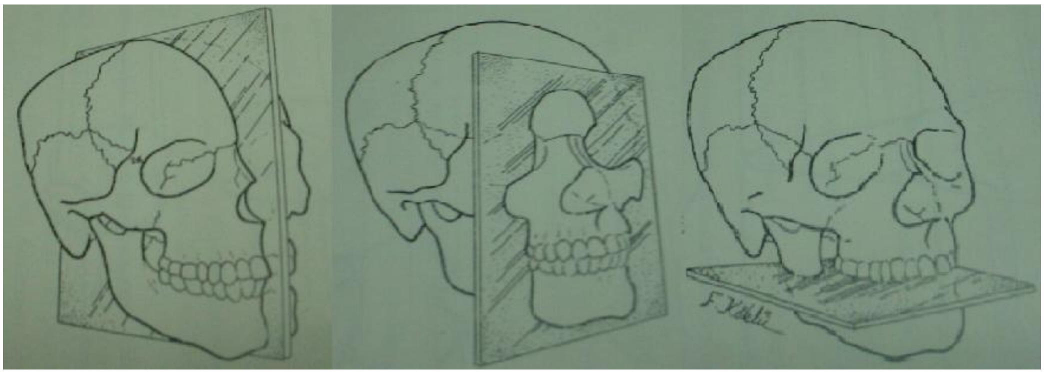
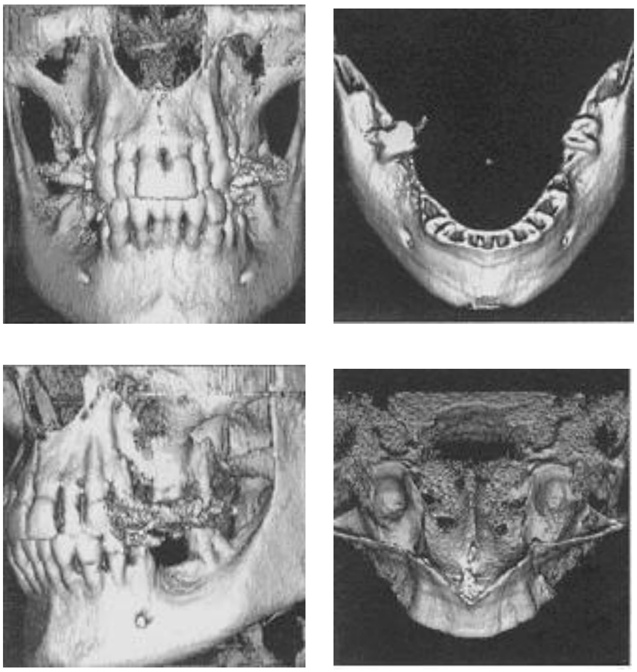


Figure 5: Sagittal, coronal (frontal), axial (horizontal) planes (44).

Multiplanar computed tomography scans provide important diagnostic information, but their two-dimensional nature can sometimes cause clinicians to have difficulty evaluating them. For this reason, there is a need to create three-dimensional images, and computer programs have been developed accordingly. Three-dimensional images can be rotated around their axes and reconstructed from different angles. In addition, they allow observation of deeper anatomical formations by removing external surfaces in the image (Figure 6).



One of the first studies in which three-dimensional tomography was applied was in cases of spinal stenosis and herniated discs. Since then, three-dimensional tomography has been used in craniofacial surgery, congenital or acquired deformities, the evaluation of intracranial tumors, benign or malignant lesions in the maxillofacial complex, cervical vertebral injuries, and hand-leg deformities. The use of CT in patients with craniofacial trauma is increasing day by day. This technique is very useful in the evaluation of TMJ, arthritis, subluxation, painful joint dysfunction, ankylosis, fractures of the mandibular condyle, and maxillofacial pathologies. Although two-dimensional computed tomography and three-dimensional computed tomography provide almost the same information about mandibular condyle fractures, three-dimensional computed tomography can better visualize separated bone fractures. These images provide very important information for surgical planning and evaluation of treatment. In addition, axial, paraxial, and cross-sectional images can be obtained in dentally programmed CT (Figure 7).

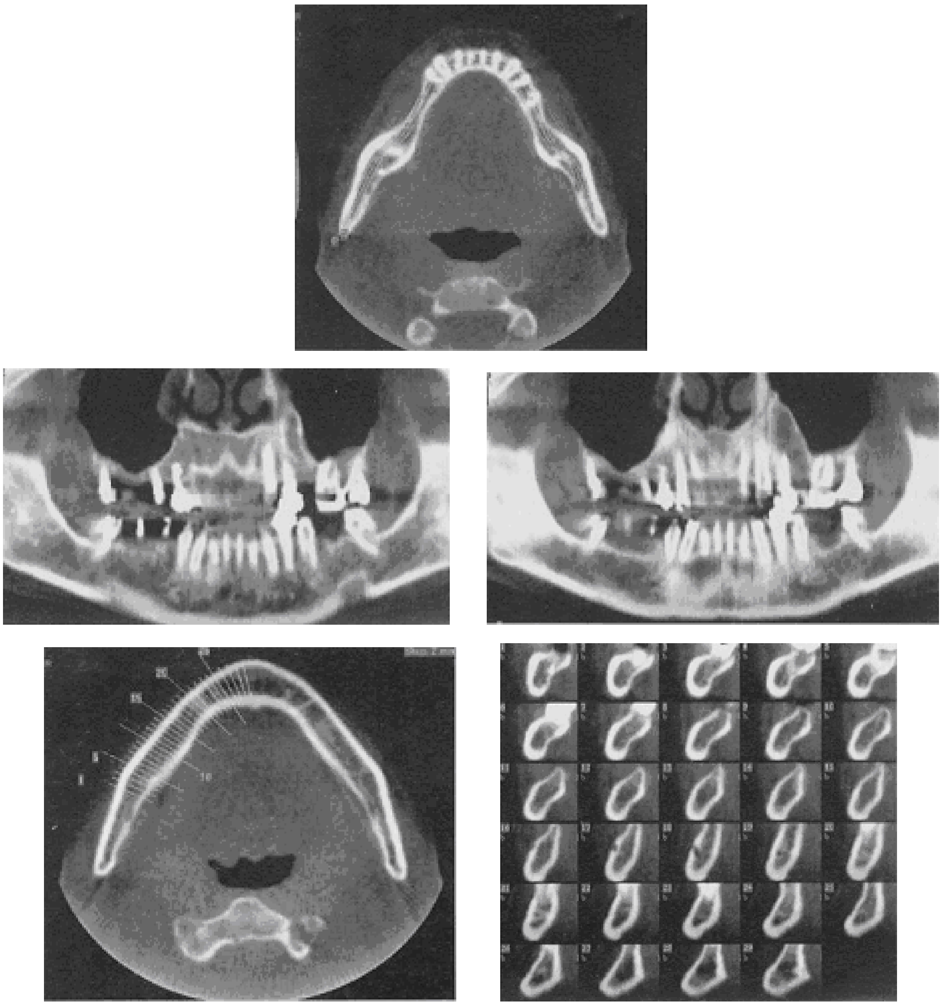


Figure 7: Axial, paraxial, and cross-sectional images on CT.

One of the most important advantages of computed tomography is the ability to measure the density of lesions. Density is evaluated between -1000 and +1000. Minuses close to zero (-10, -20) indicate fatty tissues; pluses close to zero (+10, +30) indicate fluid structures; +300, +350 indicate calcified structures. With +1000, the bone structure, which is the densest structure, is determined (Table I).

In order for the examination to be of high quality, the intravenous contrast medium must be administered in sufficient quantity, the contrast medium must be administered rapidly, the examination must be started when the desired staining level is reached, and it must be completed rapidly (spiral examination). If some of these factors are not followed, the quality of the CT scan is significantly reduced.

Table I: Various tissues degrees

of intensity on CT (6).

Tissue	**CT Value**
Water	0
Air	-1000
Bone	+1000
Blood	42-58
Hemorrhage	60-110
Thrombus	74-81
Heart	24
Cerebrospinal Fluid	0-22
Grey Matter	32-44
White Matter	24-36
Muscle	44-59
Liver	50-80
Fat	-20/-100
Lung	-300

B- MAGNETIC RESONANCE IMAGING (MRG)

Magnetic resonance imaging is an imaging method based on cross-sectioning, as in computed tomography, but using radio frequencies instead of ionizing radiation. Although the current form of nuclear magnetic resonance imaging, known and used as a spectroscopy method, is still new, systems similar to this technique have been in use for nearly 50 years. It was first described by E. Purcel and Felix Bloch in 1946 and won them the Nobel Prize in 1952. Later, in 1973, Paul Lauterbur demonstrated that the human body could be imaged with an MRI. In the last 25 years, there have been studies on small, non-destructive specimens. In the 1950s and 1960s, studies were mostly at the microscopic level, whereas today studies are at the macroscopic level. Although the use of magnetic in vivo is beginning to spread, it is still very new in the medical and dental worlds. In dentistry, magnetic resonance imaging is used as an effective diagnostic tool for TMJ dysfunctions (Figure 8).

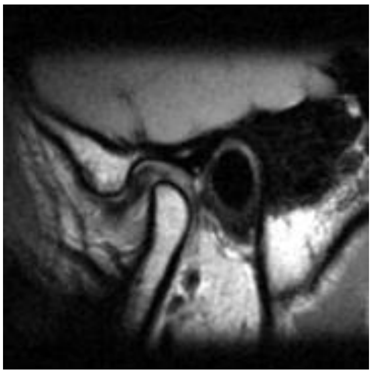


Figure 9: TMJ image on MRG.

Magnetic resonance imaging is the imaging technique with the highest contrast resolution and sensitivity compared to other diagnostic imaging modalities, and pathologic tissues can be detected very clearly. Multiplanar imaging is also possible with this technique. In other words, sections can be obtained in different plans without changing the patient's position. Thanks to this feature, the lesion can be localized in three dimensions without any discomfort to the patient.

The absence of ionizing radiation in the method also provides a great advantage over other imaging techniques. To date, no harmful biological effects of the magnetic field and radio frequencies used have been detected. This allows the technique to be used safely in all age groups.

It is also possible to obtain information about the flow dynamics of the vascular structures in the section examined in MRI. In addition, in some indications, only vascular structures can be visualized by MRI angiography without the use of contrast material. MRI angiography has become increasingly important in the study of vascular structures. Contrast agents used in MRI are much safer than iodinated contrast agents.

Instrumentation and hardware

1st Magnet - The unit that creates the magnetic field

2nd Radiofrequency source

3rd Image processor

4th Computer system

Magnet Types:

Permanent magnets: They provide natural and continuous magnetic field strength without the need to create an electrical magnetic field. These are natural magnets. They do not require any energy to generate a magnetic field. This is an important advantage of permanent magnets. However, they have two important disadvantages. First, they have thermal instability, which is a limiting factor in magnetic field strength. Secondly, an MRI magnet created with natural magnets is very heavy. For magnets with 0.3 Tesla power, this weight is up to 100 tons. The magnetic field strength increases in proportion to the weight of the magnet. Today, due to the new alloys developed, permanent magnets with lower weights can be made (8, 16).

Electromagnets (Solenoidal): These are magnets with an iron core in the center and coil systems around it. Electromagnets have a soft iron core that shows magnet properties when electric current is passed through the coils and loses these properties when the current is cut off. In this type of magnets, magnetic field strengths reaching approximately 0.4 Tesla can be obtained. The magnetic field direction obtained in permanent and electromagnets is perpendicular to the patient.

Superconducting magnets: This is the type of magnet where the highest magnetic field strength can be achieved. These magnets consist of coil-shaped conductive wires surrounding the gantry. When an electric current is passed through such a coil, a magnetic field is generated around it. In MRI, a lot of electric current is required to create a strong magnetic field. On the other hand, conductors gradually heat up due to their resistance to electric current. The higher the temperature of the conductor, the higher the resistance and, therefore, the higher the temperature. Because of this vicious circle, it is not possible to pass enough electric current through the wires. In superconducting magnets, the conductors are kept at very low temperatures, where they show zero resistance to electric current. For this purpose, liquid helium at -269°C is used. Cryostats, which contain liquid helium, provide the low temperature levels at which the coil wires can become superconducting. This allows high magnetic field strengths to be achieved by passing a lot of electric current through the conductors. The magnetic field direction in superconducting magnets is parallel to the patient.

Resistive magnets: Magnets of this kind use the superconducting magnet principle but do not have a cryostat system, so heating is a major problem and high field strengths cannot be achieved. In resistive magnets, the magnetic field direction is parallel to the patient.

Advantages of magnetic resonance imaging:

1. High soft tissue contrast,
2. Multiplanar imaging is possible,
3. No use of ionizing radiation,
4. It does not require iodinated contrast media,
5. Visualization of vascular structures,
6. Ability to evaluate cartilage tissue,
7. Visualization of the bony medulla,
8. The ability to evaluate many anatomical and functional structures in the same examination (16).

Disadvantages of magnetic resonance imaging:

1. It is very sensitive to motion artifacts,
2. The duration of the examination is quite long,
3. Bony structures and calcifications are not well visualized,
4. Patients with claustrophobia cannot be examined,
5. It is not possible to perform MRI imaging on patients with surgically implanted ferromagnetic metals,
6. Acute bleeding in the brain cannot be demonstrated due to signal characteristics,
7. It is a high-cost technique (6)

C- APPLICATIONS OF NUCLEAR MEDICINE

The morphological imaging techniques of conventional radiography, CT, MRI, and ultrasonography each have their own structural differences or the ability to image different anatomical formations in different ways thanks to their specific receptors. For example, in conventional radiography, the visualization of an object depends on the contrast produced by the absorption of X-rays. With this imaging technique, structural or anatomical changes occur as the object shows different absorptions from different regions. However, diseases do not present with specific anatomical changes. Changes can only be recognized when physical symptoms develop after some biochemical processes. In **radionuclide imaging technique**, also known as **functional imaging**, it is possible to observe physiological differences that occur after biochemical changes.

Radionuclide imaging is based on the principle of tracking radioactive elements as a result of radioactive atoms or molecules not changing their structure in the organism. Radioactive scanners measure tissue functions in vivo and thus detect chemical changes in the body caused by the disease at an early stage. The radioactive material used in this method is below the amount that would cause the death of cells. The radiation received in this imaging technique, which is an invasive method, is due to the radionuclide given into the venous circulation. It has been reported that the amount of radiation given to the body by this method is one third of the natural radiation dose to which a person is exposed in a year.

Techniques such as **PET, SPECT, lymphoscintigraphy/central lymph node biopsy** used in nuclear medicine have revealed very important diagnostic advantages. However, nuclear medicine studies in oral and dental health are not very common.

Radionuclide imaging can be used in dentistry to examine tumors and metastases of the jawbone, to diagnose osteomyelitis, trauma, fractures, arthritis, unexplained pain caused by compression of nerves, to examine pathologies of the salivary glands, and to monitor intra-bone implants, maxillofacial prostheses and grafts. Although **CT** and **MRI** provide high quality static images of soft and hard tissues, these imaging techniques can provide little information about the course of the disease. On the other hand, methods used in nuclear medicine have the ability to detect abnormalities in tissues at early stages, before morphological changes occur.

The basis of nuclear medicine is actually very simple. Radioisotopes injected into the patient are detected by special cameras after a certain waiting period in areas where radioactivity is retained and images are obtained as a result.

1. PET (POSITRON EMISSION TOMOGRAPHY)

Oncologic studies are of great importance in the development of nuclear medicine methods, which have been increasingly used in recent years. PET imaging is extremely valuable for cardiovascular, neurological, psychiatric, and oncologic diagnoses. Nuclear oncologic methods play a role in cancer patients, especially in staging and determining response to treatment, and shed light on patient follow-up and treatment planning for clinicians. The main goal of tumor imaging is to identify local or distant metastases before and during treatment, to plan appropriate treatment, to evaluate the treatment response with post-treatment studies, and to recognize recurrences at an early stage. In this respect, nuclear medicine methods have an important role in the evaluation of cancer patients.

Positron emission tomography, or PET for short (Figure 10), is considered to be the most important development in nuclear medicine in the last 10 years. With PET, the biological and metabolic functions of organs can be examined without harming the body. Cancer cases account for 75% of PET applications. Since there are biological and metabolic changes in cancer cases before structural changes occur in the body, PET imaging (Figure 19) enables earlier diagnosis. By determining the stage of cancer, a significant contribution is made to the planning of treatment.

Figure 10: PET imaging device.

Today, the most widely used radioactive substance for the diagnosis of cancer and heart disease is **fluorodeoxyglucose (FDG)**, a sugar labeled with a radioactive material called **fluorine 18**. This material behaves in the body in the same way as normal, non-radioactive glucose. It is known that non-radioactive glucose is the main nutrient for cells in the body and that cells that work hard, such as heart muscle cells and brain cells, take up and retain glucose much more. Another cell group that uses glucose a lot is cancer cells. In cancer cells, glucose utilization increases as the degree of malignancy of the cancer increases. Thus, the radioactive glucose given is very intensively retained by cancer cells in addition to normal cell groups, and cancer tissue anywhere in the body can be easily distinguished using appropriate imaging techniques. FDG accumulation is detected with the PET camera. PET is a valuable imaging modality that allows the visualization of biochemical and physiological changes at the molecular level in-vivo.

Medicare, the largest insurance company in the United States, determined after a 2-year study that if PET was used to guide the diagnosis and treatment of lung cancers, $2 billion would be saved annually. In an article published in the May 2001 issue of the American Journal of Clinical Cancer, the rate at which PET changes the patient's treatment protocol, i.e. what percentage of cancer patients who undergo PET change their treatment, was determined. It was stated that this rate varied between 45-70%, and on average, it changed the treatment in 50% of the patients and caused a different approach in the intervention to be made to the patient.

PET has many clinical uses in head and neck cancers. In oncology, PET is mainly used for localization of tumors, differential diagnosis of benign/malignant, and determination of tumor viability after treatment. Although CT and MRI can determine the morphological features of the tumor in great detail, they are insufficient for the assessment of tumor viability. PET can also show tumor blood supply, glucose metabolism, protein metabolism, oxygen concentration, nucleic acid metabolism, receptor concentration and distribution of cytotoxic agents in tumors. The ability to obtain high quality images as well as quantitative evaluation has increased the use of PET for both clinical and research purposes. PET imaging is also helpful in the evaluation of neck spread in oral squamous cell carcinoma or neck evaluation in the absence of palpable adenopathy. PET is also used in the preoperative evaluation of salivary gland neoplasms.

In principle, PET measures the regional concentrations of radioactive agents. By utilizing this information, some physiologic parameters can be easily calculated. Currently, F-18-labeled fluorodeoxyglucose (FDG) is the most commonly used PET agent. FDG is a glucose analog that is an indicator of exogenous glucose utilization. It enters tumor cells using the same transport system as glucose and, like glucose, is phosphorylated by the enzyme hexokinase inside the cell and converted to FDG-6-phosphate. FDG-6-phosphate cannot be further metabolized in the glycolytic pathway and cannot leave the cell. This is seen in tumor cells with high glycolytic activity as well as in normal myocardial and brain cells. Since FDG is a substrate that competes with glucose for glucose transport and phosphorylation, FDG uptake in tumor tissue parallels the glucose metabolism of the tumor. FDG uptake can be assessed visually, and the uptake rate can also be determined quantitatively. In general, serves as uptake rate increases as the tumor grade increases. Because glycolytic activity is high in most tumor cells, especially brain tumors, the relationship between FDG uptake rate and histological grade has been shown in detail.

FDG uptake in head and neck tumors and lymphomas correlates with the percentage of proliferative cells in biopsy specimens. This correlation has also been proven by flow cytometric studies.

With the development in imaging technology, it has become possible to perform whole body PET studies with high quality images and short acquisition times. In addition to primary and metastatic tumor imaging, PET studies can detect the response of the tumor to treatment with biochemical and physiological parameters before the lesion size shrinks in the very early period after chemotherapy and radiotherapy.

Heart disease is one of the most common areas where PET is used. PET is used to decide whether or not to operate on a coronary artery patient. With this device, it is possible to determine whether the cells of the heart muscle are viable in a patient who has suffered a heart attack and an unnecessary by-pass surgery can be prevented.

Brain diseases constitute 10% of the applications performed with PET. Alzheimer's disease, the most important cause of dementia, can be diagnosed with PET. PET examinations are also used in the treatment of epilepsy.

PET can sometimes give false positive results. FDG can also be collected in non-neoplastic tissues such as new granulation tissue, areas of inflammation, and healing scar tissue. In oral squamous cell carcinoma, false positive results can be observed two to three months after radiotherapy. False evaluations can also be obtained for conditions such as tuberculosis and sarcoidosis.

The difference between the PET method and other nuclear medicine methods is that none of the radioactive substances that emit gamma rays are found in molecules in the body, except for some of them. However, almost all positron-emitting radioactive substances are radioactive types of atoms found in molecules in the body. Atoms such as carbon, oxygen, nitrogen, and fluorine are naturally present in the body. Theoretically, the variety of radioactive molecules that can be labeled and used can be as large as the variety of molecules in the body.

Nowadays, fusion imaging studies are also performed by combining functional PET images with anatomical CT/MRI images in order to perform more accurate anatomical localization of lesions (Figure 11).

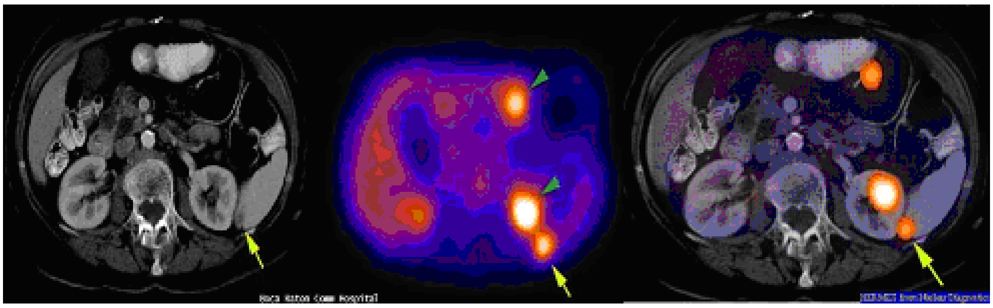


Figure 11: Determining the exact localization of the lesion by overlaying CT and PET images on top of each other, fusion imaging (14).

2. SPECT (SINGLE PHOTON EMISSION COMPUTED TOMOGRAPHY)

Single-photon emission computed tomography (SPECT) is a PET-like technique. However, Xenon-133, Tecnetium-99, and Lodine-123, the radioactive elements used in SPECT, have a longer half-life than the radioactive elements used in PET and emit single gamma rays instead of double. Tomographic images are created by detecting the rays emitted by the radiopharmaceutical given to the patient from many different angles with a gamma camera (Figure 12). A gamma camera with a rotating detector equipped with a collimator suitable for the type of examination takes static images at an angle of 3-5° along 180-360° around the body. The data from the patient is recorded by a computer, and axial, sagittal, and coronal image slices are generated. SPECT provides important information about the blood supply and the uptake of radioactive substances in the body. Perfusion study; It is used in the diagnosis of coronary artery disease when other bloodless methods are suspected in the diagnosis to determine whether patients can benefit from treatments such as coronary by-pass and balloon angioplasty and to determine and follow-up on the prognosis in patients with coronary artery disease. Using radioactive substances such as Thallium-201 and Tc-99m compounds, this test is performed on an empty stomach in two stages; stress and resting tomographic images are taken. Stress is done either by exercise testing or pharmacologically. In the test with Tl-201, loading is performed before the first images are taken, and images are taken immediately afterwards. The second image is taken 2.5–4 hours later. In the test with Tc-99m, the first image is taken

45 minutes after the radioactive substance is administered. After 2.5–3 hours, the substance is loaded again, and imaging is performed again 45 minutes later. SPECT images are less sensitive and less detailed than PET images, but they are less expensive. Fusion images can be obtained by overlapping with MRI and CT to determine the localization of lesions, just like PET (Figure 13).

Figure 12: SPECT image obtained by imaging technique.

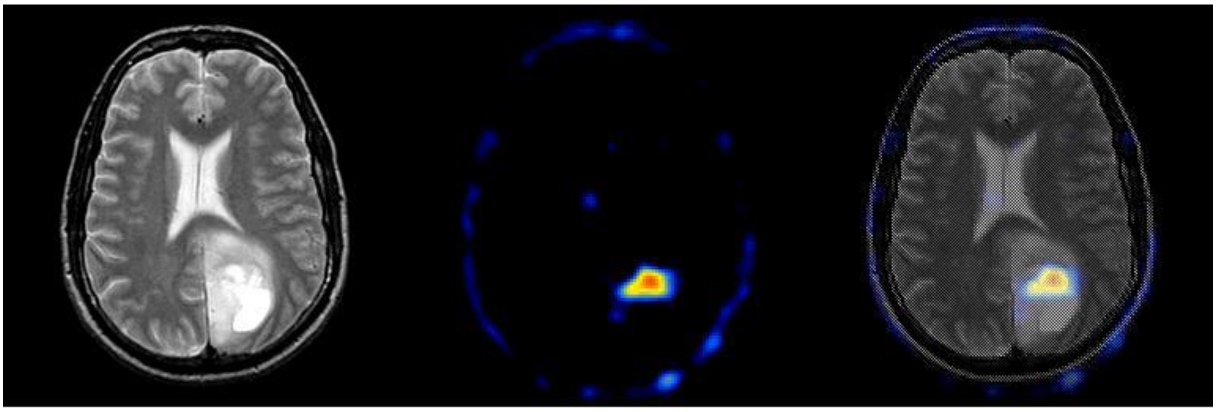


Figure 13: Demonstration of the localization of a brain tumor with MRI and SPECT images (13).

3. LYMPHOCYTINGRAPHY

One of the diagnostic methods used in dentistry is scintigraphy. The basic principle of this radiologic system is to evaluate the uptake of intravenously administered radioactive material in body tissues under Gamma cameras. Since the intravenously administered radioactive material is more retained in hypervascular tissues, it gives a darker appearance than the normal anatomical structure image in scintigraphy procedures. A lighter appearance is obtained in tissues with less blood supply. Lymphoscintigraphy is a method that provides valuable results in clinical research in head and neck cancers, especially in oral squamous cell carcinoma cases. Lymphoscintigraphy is routinely used in the grading and treatment of breast cancer and malignant melanoma (Figure 23). Tecnetium 99m sulfur-colloid is injected subcutaneously at 4-6 points around the neoplastic lesion, and the first-stage lymph node drainage and mapping of this radioactive colloid through the lymphatic channels called the sentinel node are performed. The lymphatic spread and the sentinel node are visualized with a gamma camera. An hour or two later, the surgeon localizes and removes the node with a gamma counter. The sentinel node is evaluated for metastatic disease. If there is no disease in the sentinel node, there is no disease in the remaining nodes. On the other hand, if disease is detected in the sentinel node, all the remaining nodes should be removed.

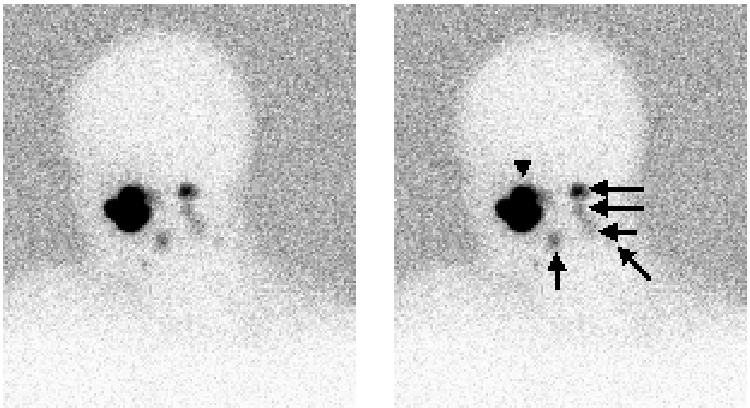


Figure 13: Image of malignant melanoma on lymphoscintigraphy.

4. BONE SCAN (BONE SCAN-BONE SYNCYTIOGRAPHY)

Bone scanning is one of the most frequently used applications in nuclear medicine (Figure 21). Bone scans are used to differentiate osteomyelitis from connective tissue inflammation and to detect primary and metastatic malignant diseases. They are also used to obtain information about the blood supply to bone grafts and to aid in the diagnosis of various metabolic bone diseases such as fibrous dysplasia, Paget's disease, osteoarthritis, and rheumatoid arthritis. Standard radiographs are known to visualize 35–50% mineral loss in bones, while bone scanning can show 10–15% mineral loss.

Tecnetium 99-methylene diphosphonate is used as a radiopharmaceutical in bone scans. The diphosphonate molecule in this radiopharmaceutical, which has a half-life of 6 hours and a total radiation dose of 0.3 rad, binds in areas of increased osteoblastic activity and vascularity. The metabolic activity of osteoblasts transports calcium phosphate throughout the ossification process. A normal bone scan should show uniform radiopharmaceutical uptake around the midline. Increased uptake is usually observed at the articular margins and vertebral regions.

Figure 14: Full-body bone scintigraphy.

Three-phase bone scanning provides diagnostic information for the physician who wants to differentiate between osteomyelitis and cellulitis. Imaging is performed in three phases during radionuclide administration. The first one is performed during the injection, the second one is performed 5 minutes after the injection, and the third one is performed 24 hours after the injection to detect bone involvement. If involvement is seen in the first two phases but not after 24 hours, the pathology is not osteomyelitis; if involvement is observed after the third phase, osteomyelitis may be considered.

In benign and malignant bone tumors, Tecnetium 99 uptake is increased in metastatic lesions that have metastasized to bone. However, it is not very specific, as the same image can be obtained in the presence of a fracture, a neoplastic lesion, or an inflammatory lesion. In metastatic bone lesions, the primary sites of the tumor are usually the lungs, chest, prostate, thyroid, and kidneys. In metabolic diseases such as fibrous dysplasia and Paget's disease, increased activity uptake can be observed on scans.

The increase in activity involvement in inflammatory conditions of the temporomandibular joint is similar to that in condylar hyperplasia. Therefore, the physician should evaluate the patient's history, examination, laboratory data, and radiologic data very carefully.

Bone scans may also show increased uptake in the usual conditions. For example, in active periodontal diseases, increased radiopharmaceutical uptake is seen in the mandibular or maxillary alveolar processes. Increased uptake in the cervical vertebrae may be due to arthritis. In growing children, there is intense uptake in the epiphysis. Soft tissue activity can sometimes be observed in this nuclear medicine application. Soft tissue involvement in the head and neck region may be due to calcifications due to malnutrition (dystrophic), chronic inflammatory conditions, infarcts, hyperparathyroidism, hematomas, and renal failure. Involvement of the kidney and bladder is quite typical.

Bone scanning can also be used with SPECT, which can provide three-dimensional images. In this way, bone pathologies can be detected more precisely and precisely localized. SPECT images can be computerized by providing images at different angles. SPECT can be used for the early detection of temporomandibular joint pathologies.

5. ULTRASONOGRAPHY IN DENTISTRY

Ultrasonography (ultrasonic imaging) is a technique used in the field of medical imaging that allows structures inside the body to be visualized with high-frequency sound waves. Ultrasonography is based on the principle of sending sound waves through a device called a transducer and receiving the reflected sound waves. These sound waves are called "ultrasonic" because they are at a high frequency that the human ear cannot hear.

Ultrasonography devices send sound waves through transducers placed on the body surface or implanted inside the body. These waves hit the tissues inside the body and are reflected. The reflected sound waves are received by the transducer and processed by a computer to create images of the structures inside the body. These images are projected on a screen in real time and can be viewed live.

Ultrasonography is capable of imaging many structures within the body. These include organs (liver, kidneys, heart, etc.), muscles, joints, veins, lymph nodes, thyroid gland, uterus, and fetus for pregnancy monitoring. In addition, invasive procedures such as biopsies can be performed under ultrasound guidance.
Ultrasonography has many advantages.

Ultrasonography is based on the principle that sound waves are reflected by tissues inside the body. These sound waves have frequencies, usually ranging from 2 to 18 megahertz (MHz). Higher frequencies provide higher resolution images but cannot penetrate deeper, while lower frequencies can penetrate deeper but offer lower resolution.

Ultrasonography devices produce and receive sound waves through a device called a transducer. The transducer is made of piezoelectric crystals and vibrates when an electric current is applied, which causes sound waves to be produced and received. The transducer comes into contact with the body through a gel placed on the body surface or inserted inside the body.

When the sound waves hit the tissues inside the body, they are partly reflected, partly absorbed, and partly transmitted. The reflected sound waves are received by the transducer and processed by a computer. This process determines the location and characteristics of different tissues based on the intensity and duration of the reflected sound waves. This information is converted into an image by the computer and projected onto a screen.

Ultrasonography devices usually provide real-time imaging. This means that the transducer is constantly sending and receiving sound waves, which are quickly processed and projected onto the screen. This allows tissues and organs to be visualized as they move live during ultrasonography.

Ultrasonography devices are equipped with various settings and modes. These include imaging depth, focal length, gain adjustment, zoom, color doppler, and power doppler. These settings are used to improve image quality and adjust it to suit specific clinical scenarios.

1.1. Essentials of Ultrasonography

Ultrasonography (US) is performed using the physical properties of ultrasound, i.e., acoustic waves with a frequency above 20 000 Hz (20 kHz). The normal human hearing range of a healthy individual is between 16 Hz and 20 kHz. Ultrasound waves are therefore all acoustic waves with frequencies higher than the threshold of human perception of sound. In clinical practice, sound waves with a frequency of 2 to 30 MHz propagate through the patient's body. Unlike electromagnetic radiation, such as X-rays, ultrasound waves require a deforming elastic medium for propagation. When oscillation is transmitted, energy transfer takes place.

The source of ultrasound is an end, also called a transducer, which contains piezoelectric elements, usually composed of barium titiate or thick zirconate. These crystals or ceramic elements have special properties, i.e., when electric current is applied to the piezoelectric element, it contracts and at the same time emits an acoustic wave. The current is proportional to the pressure force. The change in direction and depth of focus of the ultrasound waves is adjusted using phased array techniques. When the piezoelectric crystal is extended, the voltage reverses.

Acoustic waves are characterized by velocity, wave length, frequency, and intensity. Velocity is equal to the product of the multiplication of frequency (in Hertz) and wave length (in meters). The speed of ultrasound waves in the human body is estimated at 1540 m/s. This is an average velocity value in tissues, similar to an acoustic wave propagating through water. The transmission of ultrasound in soft tissues and fluids occurs as length waves, meaning that the direction of wave propagation is the same or opposite to the direction of transport of the medium. In bones, length-wave propagation is accompanied by transverse waves. The speed of the acoustic wave is characteristic of the medium in which it propagates. Therefore, when passing through tissue interfaces, only the wave length changes, and the frequency determined by the source is not affected.

The intensity of the ultrasound beam affects the examination range, i.e. the depth at which imaging can still be performed. The intensity determines the amount of energy transmitted by a wave in one second per unit of area at right angles to the direction of wave propagation.

The ultrasound field generated by the piezoelectric crystal is divided into two parts - the near field and the far field. In near fields, the beam width is constant and the beam shape resembles a cylinder, while in far fields, the beam differs. The structure of the ultrasound field in nearby fields is inhomogeneous due to the erosion and interference of spherical partial waves propagated by different parts of the piezoelectric element. The magnitude of the near field increases with a larger probe but also increases with sonde frequency.

Since the patient's tissue is not homogeneous, ultrasound encounters different tissue interfaces and various internal structures (fluid collections, calcifications, gas bubbles, and discontinuities in tissues). The resistance of tissues varies, and for soft tissues, its values are similar to those of water. Interactions with different regions in terms of acoustic impedance led to changes in the properties of the returned waves compared to the original propagating ultrasound wave. Inside the objects under investigation, physical phenomena similar to those applied in optics occur. These phenomena include reflection, orientation, tearing, dispersion, and absorption by the release of thermal energy. Strong reflections occur when impedancially very different areas are imaged, such as the interfaces between soft tissue and bone and the junctions between soft tissue and air. Reflection depends on the angle of incidence of the acoustic wave - when it strikes the object under investigation at the right angle, the reflection is strong. On the contrary, a lower angle leads to partial reflection and less reflection back to the probe. As a result of propagation and absorption, attenuation of ultrasound waves occurs, which reduces the penetration depth of an acoustic wave. Propagation is responsible for creating the internal image of tissues, and coarser surfaces produce more propagation. Refraction is observed in the case of differences in the speed of acoustic waves in two regions of the imaged object.

In the B-conversion, so-called echogenicity is evaluated. A region that produces strong sounds is called hyperechoic, whereas regions without internal sounds are called anechoic. Hypoechoic lesions are characterized by lower echogenicity than the surrounding structures, while areas with the same or comparable echogenicity are called isoechoic. Post-acoustic shadowing occurs when the ultrasound beam is completely reflected from the outer surface of a structure, such as a condyle, or when there is very dense damage, such as calcification. When ultrasound beams travel through a very low-density lesion, such as a cyst, the fluid content does not reflect the ultrasound, so a greater proportion of the beams reach the tissues located below the sum of the fluid, and more echo is generated behind the lesion. This appearance is called post-acoustic enhancement. A-mode (amplituded mode) is simpler than B-mode because it does not show the distribution of echoes on a two-dimensional cross section, but presents them as the plotted amplitude of peaks compared to time as a function of depth. In this type of presentation, the probe is placed on the surface of the skin and does not move during the examination. Therefore, only moving objects will produce images in the form of echo amplitudes. This mode is used in ophthalmology to estimate the distance between different parts of the eye.

In M-mode (also called motion mode, Time-Motion mode) the presentation is also stationary and only a single selected ultrasound line is emitted and received. All US reflective objects are displayed on the screen along the time axis. In such pictures the echoes are displayed in pixels and their brightness corresponds to the magnitude of the echo width. The very high sampling rate in this mode is advantageous as it enables the detection and measurement of very fast movements. M-mode is mostly used in cardiology.

Medical Harmonic Imaging (THI) is based on the non-linear propagation properties of ultrasound in the tissues under investigation. The shape of the ultrasound wave is distorted due to the unevenness of the wave propagation speed - i.e. the high-pressure part of the wave is faster and the low-pressure part of the beam is slower. The difference in the shape of the wave produces tissue harmonics, where the frequency is multiplied - either fundamental or transmitted. Subsequent harmonics are characterized by reduced amplitude, so only the second harmonic is sufficient to create an image. The THI technique increases the signal to noise ratio, reduces artifacts from reverberations and increases both axial and lateral resolution. US elastography allows the stiffness of tissues to be assessed based on the analysis of their shape change when an external stimulus is applied, such as an audible impulse emission propagating through the tissues in the form of external pressure. A colored map qualitatively represents areas of higher and lower stiffness. On some machines, measurements can be made in the form of kilopascall values of Young's moduli. The usefulness of the technique has already been proven, for example, for breast injuries, thyroid nodes, and musculoskeletal applications, and it is being investigated in the maxillofacial region, including contractile glands, lymph nodes, massage muscles, palatal tumors, tongue cancer, and TMJ disc.

1.2. Ultrasound Probes

There is a wide range of ultrasound devices available on the market, from sophisticated machines to portable machines. However, the applicability of an ultrasound device also depends on the applied probe. As mentioned earlier, waves with a frequency of 2 to 30 MHz are typically used in head and horn applications. The higher the frequency, the higher the resolution, but at the same time, the penetration depth decreases. Penetration depth is the maximum distance between the probe and the tissues that can still be visually seen without image noise. This explains why the highest frequency transducers can only be used for very superficial tissues. On the other hand, often the higher frequency probe provides higher spatial resolution than lower frequency transducers. Resolution is the smallest distance between two objects that can be recognized separately in an image. Resolution in the direction of the acoustic wave (axial resolution) is higher than resolution in the direction of wave transmission (lateral resolution). Axial resolution measures the smallest distance in millimeters between two points on the axis of the ultrasound beam and is visualized separately. Lateral resolution measures the smallest distance between two points located at an equal axial distance from the source of the acoustic waves and can be distinguished separately. The highest lateral resolution is seen in the focal region of the ultrasound beam. Axial resolution is estimated to be equal to 1.5 times the wave length, while lateral resolution is thought to be about 7–10 times lower. Contrast resolution is the ability to distinguish the acoustic impedance of different tissues and depends on the echo amplitude and attenuation of the ultrasound beam of the examined objects. The shape and size of the probe during scanning are also important. The most common transducer for head and horn applications is a line probe with a flat surface. The image shape from a line probe will be rectangular, but this shape can be expanded using the trapezoidal mode. A convex probe—the name is taken from the intricate shape—is usually used in abdominal US scans, but can sometimes be applied to the head and horn, for example, for imaging the enlarged thyroid gland. The probes differ in the size of the contact area on the surface, which is called the "footprint". A larger (longer) footprint will lead to the ability to display larger structures in an image, for example, the length dimension of the parotid gland. On the other hand, a probe with a smaller footprint conforms better to the curvatures of the head and neck, so that it remains in constant contact with the surfaces of the areas under study. A longer, larger probe will have "extreme" edges over the curved regions of the facial anatomy and will not produce an image there, as contact with the skin is lost.

Intraoral probes are useful for visualization of the tongue, floor of the mouth, gingival damage, palatal damage, massage muscles, and oropharynx. The specialized finger probe or finger tip probe is not common and is mostly described in research papers (Salmon and Le Denmat 2011). However, it can be successfully applied instead of an intraoperative "hockey stick" or "T-Type" probe. A very small intraoperative linear probe is also being tested for intraoral applications.

Transducers with frequencies greater than 7 MHz are suitable for examining superficial organs, often marked as "small parts" on ultrasound machines. In head and horn applications, frequencies are usually between 7 and 20 MHz. In the diagnosis of the TMJ, high-frequency (preferably more than 12 MHz) line probes with a relatively small "fingerprint" are applied because they provide high-resolution images with a relatively low penetration depth, which is sufficient for the examination of these superficially located joints. A 5 MHz probe may be useful in visualizing deeper structures, such as the deep lobe of the parotid. On the other hand, ultra-high frequency ultrasound (UHFUS) frequencies from 70-100 MHz are used for skin and mucosal imaging and provide resolution up to 30 μm for a 70 MHz probe, but have a maximum imaging depth of 10 mm. The application of a sector probe for investigations of oropharyngeal dysphagia is described. The 3D probe can also be used for prenatal diagnosis, especially useful in the assessment of maxillofacial birth abnormalities before delivery, which allows the pregnant woman to be referred to a specialized obstetric center. The registration of the 3D images is based on the monitoring of multiple scans obtained during the movement of the ultrasound probes performed by an operator.

Use in dentistry Developing technology leads to significant advances in diagnosis and treatment methods in the medical field. One of these advances is the use of ultrasonography in dentistry. Ultrasonography is an imaging technique that enables the visualization of structures within the body by using high-frequency sound waves. This technique offers various advantages in both the diagnosis and treatment processes in dentistry.

Diagnostic Use:

Evaluation of Periodontal Diseases: Ultrasonography is an effective tool for the diagnosis and evaluation of gum diseases (such as gingivitis and periodontitis).

The dentist can determine the severity of the disease by assessing the depth of gum pockets, the condition of the periodontal bone, and other structural changes with ultrasonography.

Cyst and Tumor Detection: Ultrasonography can be used to detect cysts, tumors, or other abnormalities in the jaw bones. This is important for an early diagnosis and appropriate treatment planning.

Evaluation of Sinus Diseases: Dentists can use ultrasonography to determine the presence and severity of sinus diseases (sinusitis, sinus cysts, etc.). This is an important step before dental implantation or other surgical interventions.

Therapeutic Use:

Tartar and Plaque Removal: Ultrasonic devices are effectively used to remove plaque and tartar from tooth surfaces. High frequency vibrations gently remove plaque and tartar from tooth surfaces and gums.

Root Canal Treatment Support: During root canal treatment, ultrasonography can assist in cleaning and shaping root canal systems. This allows for effective removal of infected tissues and better preparation of the root canal.

Use in Surgical Interventions: Ultrasonic devices can also be used effectively in surgical procedures such as cutting or shaping soft tissues. This allows for a less invasive and more precise surgical intervention, but it can also speed up the healing process.

6. THERMOGRAPHY

Thermography is a medical imaging method that works by measuring and visualizing surface temperature differences in the body. This method detects the heat produced by tissues or organs in the body due to different physiological processes such as metabolism, blood circulation and inflammation.

Thermography is performed using a thermal chamber or thermal camera. These cameras have special sensors that can detect radiation in the infrared light wavelength. The infrared radiation emitted from the body is detected by the thermal camera and this data is processed by computer software. As a result, the temperature distribution in the body is displayed as a color map or thermogram.

Thermograms visually represent temperature differences on the body surface. Warm regions are usually shown in red or yellow, while cold regions are shown in blue or green. These images can be used to identify temperature differences between tissues and potential abnormalities.

Thermography is used in many clinical scenarios. These include breast cancer screening, assessment of vascular diseases, monitoring of rheumatic diseases, evaluation of thermal injuries, and diagnosis of pain syndromes. In particular, in breast cancer screening, thermography can be used to detect abnormalities in breast tissue at an early stage.

Thermography is considered safe because it is a radiation-free and non-invasive imaging method. However, thermography has some limitations. For example, external factors (e.g. environmental temperature changes) can affect the thermogram and make interpretation difficult. In addition, thermography is considered as a supportive tool for a complete diagnosis when used in combination with other imaging modalities (e.g. mammography).