Brain tumor detection using machine learning methods

Pre-processing of normal and abnormal tissue from brain MRI

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***Abstract*—The advancement of the computerized methods had a great impact over medical diagnosis particularly on the automated system for tumor detection from brain MR images. Manual processing of the brain MR images for the detection of the abnormal tissue is a tedious and time-consuming task and are highly prone to errors due to the presence of high diversity in the appearance of the tumor tissue among a different number of patient and chances of confusion between normal and abnormal tissue is very high thus the automated system is highly appreciated. Automated systems work through first taking the input MR images of the brain then pre-processing of the images for removal of the noise as an important step in biomedical image processing. Diagnosis of the brain tumor through MR image hampered due to the presence of the artifacts and skull and the removal of these two is seen as an important step. The next most vital task is segmentation via some important segmentation methods viz. Fuzzy C-Means, Artificial Neural Network, Region Growing, and clustering to distinct the tumor from the normal tissue.**

***Index Terms*—Segmentation,Artificial Neural Network, Fuzzy C-Means, Cerebral Spinal fluid, Grey Matter,White matter,Neurotransmitter,Action Potential**

I. Introduction

The fast growth in the field of computer science and engineering had a great impact on the various sphere of our life, from the automated tool used in industry, smart classes in the educational institutions, automated systems used in the railways and flights, biometrics tools used in many offices, and much more than we can imagine and in this race, medical science is not an exception. Surgical Navigation Systems, which form an integral part of the Computer-assisted surgery(CAS).In medical research, there is a need of compiled, analysis and interpret a large number of data which may include the data collected from the laboratory test, patient data from the Intensive Care Units, management data and much more, all these data need sophisticated statistical methods which include calculation of the standard deviation, standard error, Z-Test, unpaired and paired test, and chi-square test. The manual approach is neither feasible nor practical when the data set is quite large and with the help of the computer-aided technology this large statistical calculation can be done within a shorter period with minimum error possibility. There exist several good quality statistical package which includes BMD(Biomedical Computer Package), SPSS(Statistical Package for social science), Genstat, Epic-Info, and many more for efficient computation. With the entangling of medical science with computers, an automated system called, CMD(Computer Assisted Decision making) assists directly the medical experts to make the vital decision based on the patient data and past knowledge. [1] In some sense, CMD falls under supervised learning. In Intensive Care Units for the survival of critically ill patients needs many life-supporting systems viz. Automated Ventilator, Monitoring Systems, Holter Machine, and much more. These all systems are primarily based on boolean logic, severals ICs, micro-controllers, CPUs works in parallel to support life. These days many automated systems assist the surgeons, RMIS(Robot-assisted minimally invasive surgery) systems like the da Vinci surgical system(dVSS) [2], have gained more and more attention in recent years, rather than cutting patients open, RMIS allows surgeons to operate by telemanipulation of dexterous robotic tools through small incisions, which result in less pain and fast recovery. For the proper diagnosis, many a time high-resolution images of the body parts are needed. Dedicated hardware and software are needed to generate such images. Prominent methods for biomedical image processing are CT(Computerized Tomography), MRI(Magnetic Resonance Imaging)PET(Positron emission tomography scan), Ultrasonography, and gamma cameras.

This paper focuses on the detection of brain tumors using machine learning.

A research conducted by The National Brain Tumor Foundation(NBTF) in USA shows that approximately 29K adults are detected with a primary brain tumor every year, moreover out of them 13K died every year. Especially among kids brain tumor is behind 1/4 of all death related to cancers. According to the report published from NCIS(National Cancer Institute Statistics), over the last two decades, the overall increase in the rate of carcinogens that includes brain cancer is more than 10%.In the USA the average incidence of primary brain tumors is 11 to 12 for every 100K and for a primary malignant tumor the figure is 6 to 7 for every 100K adults. [3] Brain tumor accounts for 85% to 90% of all primary CNS tumor. A brain tumor is the uncontrolled growth of the tissue cell. The cells that supply blood to the arteries are tightly bounded inside the brain which makes general laboratory tests inadequate to analyze the chemistry of the human brain. The various provisions of the biomedical image processing viz. CT, MRI, PET, Ultrasonography allow surgeons, medical experts, and researchers to analyze the brain anatomy for tumor detection without real-time surgery.

The paper focuses on the automated detection of brain tumors through machine learning. The fundamentals being involved are

1) MRI Input: The first very task is to collect the MR images of the tissues, Magnetic Resonance Imaging is a technique that uses powerful magnets to polarized and excites the hydrogen nuclei i.e. proton in the water molecules in human tissues which generates a detectable signal which is spatially encoded resulting in the images of the body.
2) PreProcessing: The input MR images contain much additional information that must be removed before further processing, viz atmospheric noise, artifacts and skull, and nonbrain elements.
3) PostProcessing: The next and the most vital task in the entire process is segmentation which is technically defined as the process of partitioning the image into homogeneous regions. Ideally, segmentation finds those sets that correspond to distinct anatomical structures or regions of interest in the image.
4) Feature Extraction and classification: The next most vital task after post-processing i.e.segmentation is feature extraction which refers to the extraction of the relevant shape information contained in a pattern so that the task of classifying the pattern is made easy by a formal procedure, concerning the results retrieved from the extracted feature the process of tumor classification is performed.
5) Image analysis and diagnosis: The final step is image analysis and medical diagnosis which is done by medical experts and surgeons for further treatment.

II. Literature Review

A. Anatomy of brain

Anatomy of brain plays a very important and crucial role in this literature because it is very important to identify the location of the abnormal tissue growth in the brain and a study on neurons,functions of neurons and neural signal generation is also important.

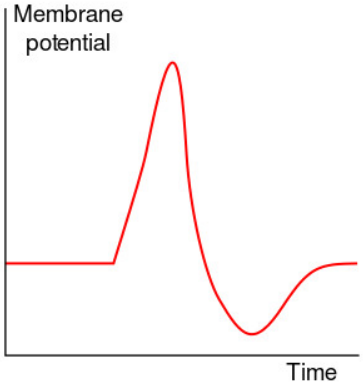
- **Basic Structure of brain** In human body brain is one of the most complex organs and it also runs some very complex processes which helps to develop the cognition of a human being.Brain is basically divided into some numbers of region and each region has it's unique duties.
  - **Frontal Lobe** The frontal lobe is the most anterior part of the brain.It is basically responsible for higher cognitive functions of human such as memory,problem solving,emotions social interactions and more.
  - **Parietal Lobe** The parietal lobe is basically situation right behind the frontal lobe.The main function of parietal lobe is that it processes the sensory information of the body.Parietal lobe contains somatosensory cortex within it for processing the sensory information.
  - **Occipetal Lobe** The occipetal lobe is basically located at the back side portion of the brain and it is basically responsible for interpreting visual stimuli and processing it.It basically gathered and interpret the visual information from the retina of the eye.
  - **Temporal Lobe** Temporal lobe is basically associated at the lower front of the brain and it basically takes sensory input and trying to derive meaning from visual stimuli,language comprehension and more.
  - **Cerebellum** The cerebellum is located behind the top part of the brain stem and is made of two hemispheres. The cerebellum receives information from the sensory systems, the spinal cord, and other parts of the brain and then regulates motor movements.It basically responsible for motor movements.

  There are also many important parts and regions of the brain but the above mentioned regions are the main regions of a human brain.
- **Basic Structure of Neuron** Neuron is the fundamental unit of information processing in brain.Our brain made up of billions of neurons.It plays a very important role in building memory,learning and other mental processes in the brain.The basic structure of a neuron of a human brain can be explained as follows
  - **Cell Body:** The cell body of a neuron also known as central cell body or soma is made up of neucleus,mitochondrion,endoplasmic reticulum.The cell body has many chemically gated ion channels on the cell membrane which helps the cell body to create electric empulses which latter flows through axon.The cell body does not contain centriols thats

why the neuron cell cannot divides and for this reason the neuron cell is not cancerous.

- **Dendrites:** Dendrites are projections of a neuron that receives signals from other neurons through synapses.It basically connected with the cell body of the neuron and pass the signal into the cell body.The transfer of information(Electric Signal) from one neuron to another neuron is achieved through chemical signals and electric impulses,that is,electrochemical signals.
- **Axon:** Axon is a long projection of neuron that conducts electrical impulses away from the cell body of a neuron through the Axon Hillock.Axons are the primary transmission lines of the nervous system,and as the bundles they help make up nerves.
- **Myelin Sheath:** Myelin Sheath is basically an insulating layer around the nerves .It is made up of protein and fatty substances.It basically works as an insulator and saves the electrical signals from being discharged.
- **Synapse:** In the Central Nervous System(CNS) synapse is a small gap at the end of a neuron that allows a signal to pass from one neurone to thr next.Synapse are found where neurons are connected with other neurons.It basically connects one neuron to another by a synaptic cleft which is a free spcae.It plays a very important role in the brain function specially memory.

- **Function of neuron** The neuron is the basic fundamental unit of information processing in the brain.It is a specialized cell which transmits information in he form of electrical signals to the other neuron.It also sends the signals to glands and muscles by which the whole body can work properly.
- **Generation of neural signals** Generation of neural signal has a very important significance to the neural communication and information processing in the brain.In the generation of neural signal the main trump card is played by electric impulses coming from the cell body through the axon and the Neurotransmitters.The whole process goes like first of all, all the small electrical impulses receiving from other neurons through synapse and through dendrites is accumulated in the cell body and for this reason the membrane potential of the cellbody changes(It basically may be positively changed or it maybe negatively changed,depend upon the neurotransmitter.Here for the sake of simplicity we are going to talk about the positively change condition).The change of the potential of the cell body allows the open of more chemically gated ion channels and that's why the change occurs more.After a particular voltage threshold of the cell body a electric impulse known as Action Potential generated in the cell body which flows through the Axon Hillock and Axon to the Synapse.After action potential reaching the Synapse the membrane potential changes and the chemically gated channels are opened up.There occurs a calcium ion influx into the synapse and it basically opened up the synaptic vesicles(Which holds the neurotransmitters) and discharge the neurotransmitters to the void region between the dendrite of the second neuron and the synapse of the first neuron.This neurotransmitters combines with the chemically gated channels of the second neuron and allows ion influx into the second neuron which lead the same process again in the second neuron.The generation of neural signals are very important basically in this way every neuron communicate with each other and processes the information.



B. Magnetic Resonance Imaging

Magnetic Resonance Imaging is imaging technique which gives a insight of the anatomy,physiological properties of the body.It also gives a detailed about the tumour anatomy,vascular supply of the body,cellular structure and more.MRI uses magnetic field instead of ionization radiation which is used by X-rays.MRI gives a detailed information about the anatomy of brain.It also gives a detailed information about the location of the brain tumour and the details of it.

- **Spinning of Protons** In a human body thermal energy causes protons to spin.At the time of MRI a strong magnetic field is applied to the body.After applying the magnetic field protons starts spinning in a special way which is known as precision. In the magnetic field protons are assume a state of parallel or anti-parallel state to the magnetic field.The protons with high energy are basically anti parallel to the magnetic field and the protons with lower energy are parallel to the magnetic field.
- **T1 and T2 Relaxation Time** To receive information signals from the brain the precision of protons is disturbed by an external magnetic field imposed perpendicular to the direction of the main magnetic field.after imposing this magnetic field the protons are moved to the higher energy state.After some time (say T) the protons are moved to their equilibrium or original state.This time T is known as Longitudinal or T1 Relaxation Time.After imposing the external magnetic field the protons are spinning in the same phase.After withdrawing the external magnetic field the time taken of protons for de-phasing is known

as Transverse or T2 Relaxation Time.Relaxation time is the characteristic time it takes the spin to recover after being disturbed from equilibrium.Biological Matter has different but consistent T1 and T2 relaxation times.By observing these differences we can estimate the characteristics of the cell or tissue.The constructed MRI image is different in both T1 and T2 Relaxation Times.In case of T1 wieghted MRI image the CSF is dark and blood and fats are bright and in the case of T2-weighted MRI image the fat is intermediate bright and CSF is bright.

- **Repitition Time(TR) and Echo Time(TE)** TR and TE are the pulse sequence parameters and stands for Repitition Time and Echo Time.The repetition time (TR) is the time from the application of an excitation pulse to the application of the next pulse. It determines how much longitudinal magnetisation recovers between each pulse. It is measured in milliseconds.TE represents the time from the center of the RF-pulse to the center of the echo.Theses are basically used to measure the T1 and T2 RElaxation times respectively.
- **ImageConstruction** MRI uses magnetic fields and radio waves to measures how much water is in different tissues of the body, maps the location of the water and then uses this information to generate a detailed image. The images are so detailed because our bodies are made up of around 65 percent of water,so we have lots of signal to measure.By using this signals and varying the intensities of the signal we can create a detailed image of the region of concentration.

C. Preprocessing

Automated Brain tumor detection systems are known as Computer-Aided Diagnosis(CAD) which consists of the above mention steps viz. Preprocessing followed by Post Processing(Segmentation) hence after all the detection strategies feature extraction, image analysis, and finally the diagnosis. Preprocessing includes those tasks that are essential prior to the actual goal of partitioning the image into regions of similar anatomical interest and extraction of desired information from the segmented regions [4]. It often includes geometrical correction of the original image i.e. measures to avoid geometric distortion by establishing the relationship between image coordinates and geographic coordinates systems. Segmentation is hammered by the presence of

- **Noise** Noise is an unwanted random variation of brightness, intensity, or any other type of color information in images that got attached with our true image during acquisition, compression, and transmission. This unwanted information can lead to the loss of image information and distortion. The presence of noise makes further image processing tasks difficult.
- **Blur Low Contrast**
- **The Bias Field** Bias field is a smooth low-frequency undesirable signal that hammered the MRI, in particular, those by the old machine due to the inhomogeneities in the existing magnetic field of the MRI machine [5], they blur the image, thus reduced the high-frequency contents of the image viz. edges and contour and change the intensity values of the pixels and thus the same tissue has different grey level distribution across the image.
- **The partial volume effect** The partial volume effect is the loss of contrast between adjacent tissue due to the insufficient resolution [6] so that more than one type of tissue occupies the same voxel(unit of graphical information in 3D space).

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Noise is mostly additive but sometimes it can also be multiplicative which indicates that the brighter the area is, the noisier it's.
It can be model as $A(X,Y) = H(X,Y) + B(X,Y)$ where A(X,Y) is the function of the noisy image,H(X,Y) is the function of noise and B(X,Y) is the function of the original image.Broadly there are three different classes of noise

1) **Gaussian Noise** It's a statistical noise having a probability density function equal to a normal distribution also known as Gaussian Distribution, where the random Gaussian function got added to the image function which gives rise to this noise. Gaussian noise is additive and it's independent of the individual pixel and signal intensity. It arises out of thermal vibration of the atom and discrete nature of radiation of warm objects. Gaussian noise is also known as electronic noise as it arises in amplifiers or detectors,i.e. when we try to amplify some portion of the image that contains more noise than non amplified portion. The amount of noise present in the image is closely related to the standard deviation of the probability distribution. Noise magnitude is directly proportional to the standard deviation.
2) **Impule noise**Impulse noise consists of a short spike of power having an approximately flat frequency response over the spectrum range of interest. Specifically, in the case of salt and pepper noise, the most general type of impulse noise contain dark pixel in the bright region and vice versa. It's caused by several sources such as switching of relays in the electromechanical telephone exchange, dead pixels, bits error in transmission. Although it's tolerant to human ears it can cause several serious error rate problems in data or digital circuits. Impulse noise can be further classified into three different subclasses
    - **Salt Noise :** Addition of random bright(with 255-pixel value) all over the image.
    - **Pepper Noise :**Additon of random dark(with 0-pixel value)all over the image.
    - **Salt and Pepper noise :**Addition of both random and dark pixel i.e (pixel with value 0 and 255) all

over the image. Statistically, it drops the original data value and thus it's also known as data drop noise.

3) **Poisson Noise:** It occurs due to the statistical nature of electromagnetic waves such as x rays, visible lights, and gamma rays. The random fluctuations of photons resulted in the gathering of spatial and temporal randomness. It's also called quantum(photons) noise or shot. [**?**]
4) **Speckle noise:** Speckle noise is a granular noise that arises due to the environmental factor on the imaging sensor during image acquisition which degrades the quality of the medical ultrasound and optical coherence tomography images.It results due to constructive and destructive pattern seen as bright and dark dots in the images.

Apart from the noise removal, there is one more important barrier to the automated brain tumor detection method segmentation method, the skull portion of the brain and it's removal though not compulsory but seem like an important step. Artifacts are seen as an obstacle to every post-processing techniques and thus its removal is seen as a mandatory step but skull pose an obstacle only in the detection of some form of an abnormality like edema, tumor, stroke lesions, and hemorrhage lesions but for a particular form of hemorrhage we need to compute the distance of abnormal region from the skull.

Apart from the removal of noise(denoising) image filtering and enhancement also form an integral part of the preprocessing stage. Image enhancement is the process of manipulating the image so that the processed image is more suitable and useful for a particular application than the original one. It includes noise reduction, intensity and contrast manipulation, edge sharpening, filtering. The goal of the enhancement technique is to make the enhanced image more useful to a certain application but it is worth to note that it doesn't alter the inherent information contained in the image. Thus over the enhancement of some regions of the image poses a great difficulty in the contrast enhancement method as these may lead to an increase in contrast and consequently alteration in the anatomical information. Median filter, Low pass filter, Gradient-based method, Prewitt edge-finding filter, Nonlinear filter,v filter are some of the prime filtering methods. Image denoising Image denoising is the method of removal of noise from a noisy image to restore the original image prior to9 the addition of the noise. Image denoising is a classical problem that can be viewed from a mathematical perspective $y = x+n$ where y is the observed noisy image,x is the unknown clean image, and n represent the noise element for instance Additive White Gaussian Noise(AWGN) with a particular standard deviation say σ_n which can be estimated using several methods viz. median absolute deviation, block-based estimation, and principal component analysis(PCA) methods. Although image denoising is a classical problem it remains an open challenge. The main reason is due to the inverse nature of the problem from the mathematical perspective and the solution is not unique. The prime objective of the image denoising methods is to reduce noise as much as possible with minimal loss of original information and maximal SNR ratio.

1) Signal Noise Ratio(SNR): Signal to Noise Ratio(SNR) is a standard or factor used to measure the performance of an MRI system. In terms of formal definition Signal to noise ratio or SNR is the ratio between the desired information or the power of a signal and the undesired signal or the power of the background noise. Mathematically

$$S.N.R. = \frac{Power of the Signal}{Power of the Noise}$$

SNR is a measuring parameter used to measure the amount of noise that is present in the MRI image. The prime two sources of noise in the MRI image are

1) Molecular movement: Human body consists of charged particles whose movement creates electromagnetic noise.
2) Electrical Resistance: The various electric components viz. receiver coils, data cables, transistor, diodes, and all other electronic components in the MRI System has some resistance which produces noise.

The prime factors which determine the magnitude of noise in an MRI Image are

1) Coil: Number of elements, type, and size of the coil determine the magnitude of the noise in the resultant MRI Image.
2) Bandwidth: The Bandwidth of the EMR waves differs in each pulse sequence. Factors affecting the signal to noise ratio

1) Field strength: Field strength is directly proportional to the signal to noise ratio(SNR). Increasing the magnetic field will increase the magnetization by aligning more protons to the main axis. This results in an overall increase of the signal which henceforth increases the magnitude of the signal to noise ratio. Increasing field strength will increase the signal and hence will provide a better contrast to the anatomical structure.
2) Radiofrequency coil and SNR: Due to the availability of a large number of Radio Frequency transmitter and receiver coil, the selection of an optimal RF transmitter and coil is a crucial factor. For the maximum value of the SNR, the RF coil should be as close as possible to the anatomical portion being scanned. In most MRI systems there is a dedicated coil for each anatomical structure. The magnitude of the SNR also depends on the number of the transmitter and receiver coil present in the system. The higher the number of the transmitter and receiver coil, the more is the magnitude of the signal to noise ratio and hence better-contrasting features.
   The SNR ratio also depends on the BMI of the patient, the two quantity is inversely proportional to each other the reason is that high Body Mass Index would shift the

center of interest of the anatomical structure from the receiver coil and hence it would lead to a low contrasting feature of the region of interest.

3) Tissue Characteristics and SNR: The magnitude of the SNR and hence the image quality had a direct relationship with the anatomical region of interest. It particularly depends on the magnetic characteristics of the tissue, tissue with more number protons will produce a strong signal and hence have a higher value of SNR ratio. Infants tissue have more protons concentration and thus have a high SNR ratio than an adult.
   Fat saturation often leads to grainy, low SNR images, and any reduction of the signal from the fat portion reduces the overall signal intensity of the anatomical region of interest.
4) Repetition time(TR) and Signal to Noise Ratio(SNR): In the theoretical basis of the Magnetic Resonance Imaging there are two fundamental terms related to the radio frequency pulse viz. Repetition time(TR) and Time to echo(TE). Repetition time is the amount of time between two successive pulse sequences applied to the same slice. Time to echo is the time elapsed between the delivery of the eRF pulse and the corresponding receive of the echo signal.
   It's quite obvious if we increase the frequency of the radio frequency signal(RF pulse) more frequently the signal hits the tissue and hence it would lead to an increase in the value of the signal to noise ratio or SNR.however increasing TR valuer beyond a certain limit will eventually reduce T1 effect. An optimum value of TR is very important in the case of T1 weighted imaging to have the best possible tissue contrast.
5) Time to Echo(TE) and Signal to Noise Ratio(SNR): Time to echo is the time elapsed between the delivery of the RF pulse and the corresponding receive of the echo signal.
   It's quite obvious that minimum the time to receive the echo signal from the anatomical parts of the body, better would be the Sound to Noise Ratio(SNR). It can be viewed as a feedback system where one waits for the feedback signal, the lesser the time it takes for the feedback the better it would be.
   However be decreasing the time to echo beyond a certain limit will eventually reduce the T2 effect and thus reduction of the TE should only be used for T1 weighted images.
6) Flip angle and Signal to Noise Ratio(SNR): Flip angle is the phenomenon where the hydrogen proton shift from its longitudinal plane Z-axis or static magnetic field B_0 to its transverse XY axis due to excitation caused by RF pulse. A high transmitter will increase the magnitude of the RF pulse and can be used to effectively reduce scan times in patients with claustrophobia and patients with urgency. This will allow the users to reduce the TE and TR values manually and hence scan time however this approach will results in more noise and increase the potential of the peripheral stimulation. Thus SNR increases with an increase in the magnitude of the flip angle.
7) Slice thickness and Signal to Noise Ratio(SNR): Magnitude of the SNR is directly dependent on the slice thickness this follows from the principle that increasing the slice thickness will increase the voxel size and this would result in an increase in the amount of the signal received from the individual voxel. However, an increase in the slice thickness will reduce the spatial resolution and increase the partial volume effect.
8) Slice gap and Signal to Noise Ratio(SNR): Slice gap is the distance between two adjacent slices and it's calculated as the percentage of the slice thickness. Slice gaps are necessary to avoid slice overlapping due to the imperfection of the RF pulse. The RF pulse is so imperfect that ba rectangular slice will never produce rectangular signals and removing the slice gaps the two adjacent slice are bound to overlaps at the edges and this would lead to a phenomenon known as cross-talk(exciting a small portion of the adjacent slice due to slice overlapping)the cross talk will result in sin a saturation effect and this will significantly reduce the magnitude of the SNR.
   Thus slice gap will increase the magnitude of the SNR but in most cases, one has to comprise between an optimal SNR and the missed information caused due to a large slice gap. In most practical applications an interslice gap of 25-50 % of the slice thickness is used. However, it is worth to note that increasing the slice gap beyond a certain limit usually above 50 % can lead to problems, misregistration. In addition to increasing the slice gaps to increase the SNR, interleave option can also be used which scan the slices in some order i.e. all the odd slices in the first acquisition followed by all the even number of slices in the second acquisition.
9) Matrix size and Signal to Noise Ratio(SNR): Increasing the matrix size will eventually reduce the magnitude of SNR. An increase in the size of the matrix will lead to the reduction of the voxel size and hence reducing the amount of signal received by individual pixels. The smaller pixel will receive less signal which in turn produces an image with low SNR. Conversely decreasing the matrix size will reduce the spatial resolution and hence produce blurry images. Thus the selection of a proper matrix size for the production of optimal quality images is a crucial factor.
10) Field of View(FOV) and Signal to Noise Ratio(SNR): Field of view(FOV) refers to the two-dimensional or three-dimensional area over which the final MRI image is acquired or min other words it is the size of the displayed image. The field of view should be as much as to contain the region of intere4st as possible. If FOV is smaller than the region of interest the technician may have to obtain the images in stages, imaging one part of the region and then moving on to the next. One may

expect that a smaller FOV may offer high-resolution images but they may have a lower measured signal. A large FOV can image a larger area of the body with less for positioning.

The field of view may be adjusted before imaging a wider FOV may allow the scanner to gather more data. The FOV size can be decreased by the technician focusing on some particular body part, tissue structures, or organ.

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