INTRODUCTION

Acoustic Noise and MRI Procedures

Various types of acoustic noise are produced during the operation of an MR system [1-8]. Problems associated with acoustic noise for patients and healthcare professionals include annoyance, verbal communication difficulties, heightened anxiety, temporary hearing loss and, in extreme cases, the potential for permanent hearing impairment.[9-13]

Acoustic noise may pose a particular problem to specific patient groups.[14-34] For example, patients with psychiatric disorders may become confused or suffer from increased anxiety[14] because of exposure to loud noise. Sedated patients may experience discomfort in association with high noise levels.

In addition, neonates may have adverse reactions to acoustic noise. Reeves MJ, et al. (2010)[35], conducted a study to address this issue, the findings suggested that exposure of the fetus to 1.5-T MRI during the second and third trimesters of pregnancy is not associated with an increased risk of substantial neonatal hearing impairment or cochlear injury.

Hearing and the Impact of Acoustic Noise

The human ear is a highly sensitive wide-band receiver, with the typical frequency range for normal hearing being between 20-Hz to 20,000-Hz. [10,11] The ear does not tend to judge sound powers in absolute terms, but assesses how much greater one power is than another.

Noise is defined in terms of frequency spectrum (in Hz), intensity (in dB), and time duration.[10,11] Noise can be steady-state, intermittent, impulsive, or explosive. Transient hearing loss may occur following exposure to loud noise, resulting in a , reported temporary shifts in hearing thresholds in 43% of the patients scanned without ear protection or with improperly fitted earplugs. Recovery from the effects of noise occurs in a relatively short period of time. However, if the noise insult is particularly severe, full recovery can take up to several weeks. If the noise is sufficiently injurious, a permanent threshold shift at specific frequencies may occur. The logarithmic decibel scale, dB, is used when referring to sound power.

Table (I) outlines the possible causal connections. Many of these connections are already reasonably established and some suggested by the model are less clearly established. There is a relationship between sleep loss and stress with possible causal connections in both directions. It is less understood how reaction modifiers, including attitude to the noise source, noise sensitivity, and perceived control over the noise consciously or unconsciously influence an individual's reaction to noise.[12]

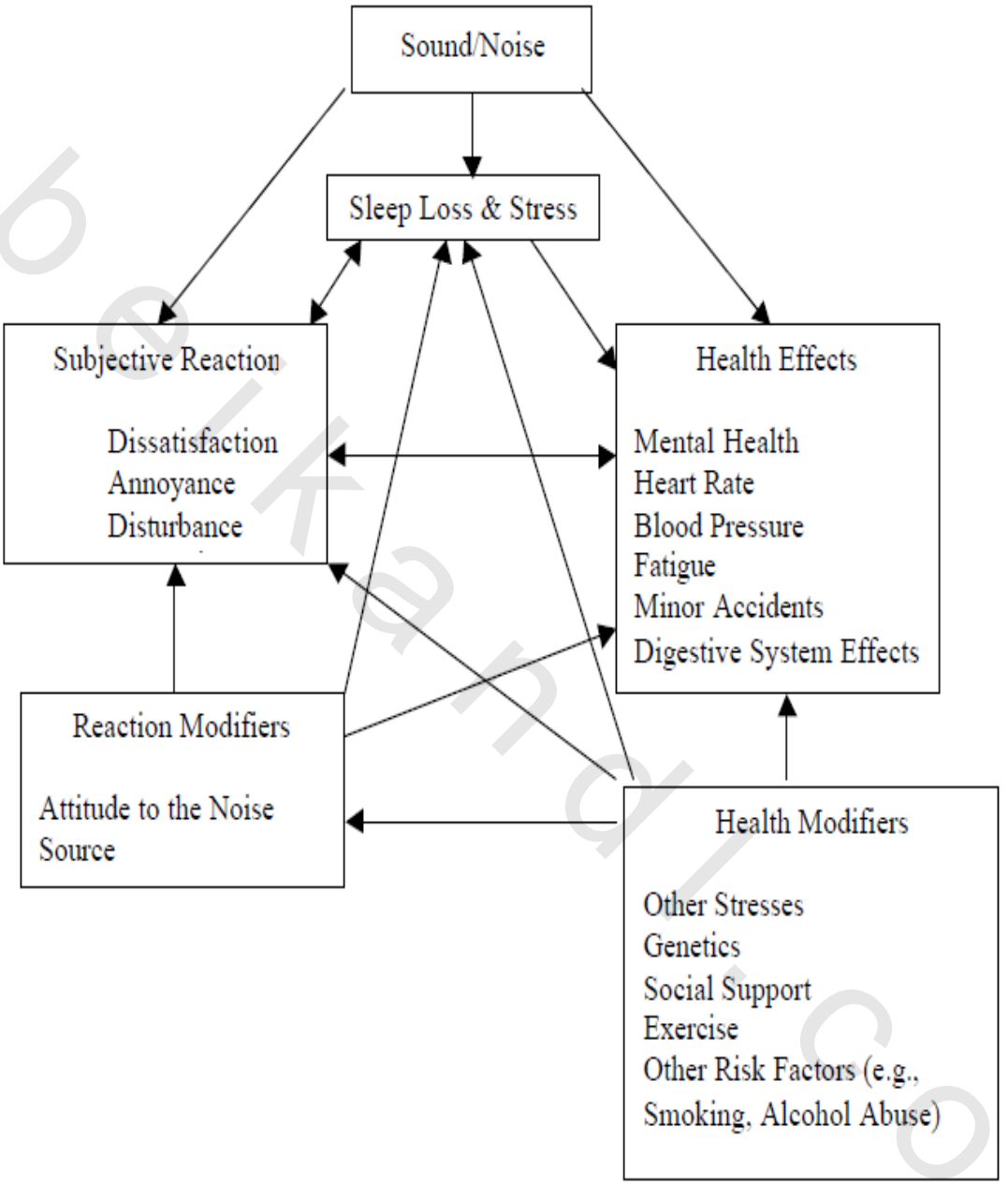


Table (I): A Model of the Causal Connections between Noise, Community Reaction, Modifiers and Health Effects. Source: Adapted from "The influence of subjective reactions to noise on health effects of the noise" by R.F.S. Job, Environment International, 1996**.**

MRI-Related Acoustic Noise

The gradient magnetic field is the main source of acoustic noise associated with an MR procedure. This noise occurs during the rapid alterations of currents within the gradient coils. These currents, in the presence of the strong static magnetic field of the MR system, produce significant (Lorentz) forces[36] that act upon the gradient coils. Acoustic noise, manifested as loud tapping, knocking, chirping, squeaking sounds, or other sounds is produced when the forces cause motion or vibration of the gradient coils as they impact against their mountings which, in turn, flex and vibrate.

Alteration of the gradient output (rise time or amplitude) by modifying MR imaging parameters causes the acoustic noise to vary[4]. Noise tends to be enhanced by decreases in section thickness, field of view, repetition time, and echo time. In addition to dependence on imaging parameters, acoustic noise is dependent on the MR system hardware, construction, and the surrounding environment. Furthermore, noise characteristics have a spatial dependence. For example, noise levels can vary by as much as 10 dB as a function of patient position within the bore of the MR system [4]. The presence and size of the patient may also affect the level of acoustic noise.

Characteristics of MR System-Related Acoustic Noise

Gradient magnetic field-induced noise levels have been measured during a variety of pulse sequences for MR systems with static magnetic field strengths ranging from 0.35 to 4-Tesla. For example, Hurwitz et al(1989) [37], reported that the MR imaging-related sound levels varied from 82 to 93 dB on the A-weighted scale and from 84 to 103 dB on the linear scale.

Later studies[38] performed using a variety of MR parameters including "worst-case" pulse sequences that applied multiple gradients simultaneously (e.g., three-dimensional, fast gradient echo techniques) reported that these are among the loudest sequences, with acoustic noise levels that ranged from 103 to 113 dB (peak) on the A-weighted scale.

Additional studies measured acoustic noise generated by echo planar imaging (EPI) and fast spin echo sequences.[39-42] Echo planar sequences tend to have extremely fast gradient switching times and high gradient amplitudes. Shellock et al (1998) [4], reported high levels of noise ranging from 114 to 115 dB A on two different high field strength (1.5-Tesla) MR systems tested during EPI sequences with parameters selected to represent "worst-case" protocols. At 3-Tesla, Hattori et al (2007) [43], recorded sound levels that ranged from 126 to 131 dB on a linear scale, recommending the use of both earplugs and headphones for ear protection relative to the use of 3-Tesla MR systems when certain pulse sequences are used.

Acoustic Noise and Permissible Limits

In general, acoustic noise levels recorded in the MR environment have been below the maximum limits permitted by the Occupational Safety and Health Administration of the United States, especially when one considers that the duration of exposure is an important factor that determines the effect of noise on hearing.

The U.S. Food and Drug Administration [44] released guidelines for acoustic noise levels that should not be exceeded in association with the operation of MR systems, as follows:

Sound Pressure Level - Peak unweighted sound pressure level greater than 140 dB. A-weighted root mean square (rms) sound pressure level greater than 99 dBA with hearing protection in place. [44]

While the acoustic noise levels recommended for patients undergoing MR procedures on an infrequent and short-term basis may appear to be somewhat conservative, they are deemed appropriate when one considers that individuals with underlying health conditions may have problems with noise at certain levels or frequencies. Acoustic noise produced during MR procedures represents a potential risk to such patients. As previously mentioned, the possibility exists that substantial gradient magnetic field-induced noise may produce hearing problems in patients who are susceptible to the damaging effects of loud noises.

The exposure of staff and other healthcare workers in the MR environment is also a concern (e.g., those involved in interventional MR procedures or who remain in the room for patient management reasons). Accordingly, if loud noises exist in the MR environment, staff members should routinely wear ear protection if they remain in the room during the operation of the scanner. In the United Kingdom, guidelines issued by the Department of Health recommend hearing [43] protection be worn by staff exposed to an average of 85-dB over an eight hour day.

Other Sources of MR System-Related Acoustic Noise

Radiofrequency hearing: [44-46] When the human head is subjected to pulsed radiofrequency (RF) radiation at certain frequencies, an audible sound perceived as a click, buzz, chirp, or knocking noise may be heard. This acoustic phenomenon is referred to as "RF hearing", "RF sound" or "microwave hearing".

Thermoelastic expansion is believed to be responsible for the production of RF hearing, whereby there is absorption of RF energy that produces a minute temperature elevation (i.e., approximately 1×10^{-6} ^{0}C) over a brief time period in the tissues of the head. Subsequently, a pressure wave is induced that is sensed by the hair cells of the cochlea via bone conduction. In this manner, a pulse of RF energy is transferred into an acoustic wave within the human head and sensed by the hearing organs.

With specific reference to the operation of MR scanners, RF hearing has been found to be associated with frequencies ranging from 2.4- to 170-MHz. The gradient magnetic field-induced acoustic noise that occurs during an MR procedure is significantly louder than the sounds associated with RF hearing. Therefore, noises produced by this RF auditory phenomenon are effectively masked and not perceived by patients. Currently, there is no evidence of any detrimental health effect related to the presence of RF hearing.

Noise From Subsidiary Systems: [47-49] Patient comfort fans and cryogen reclamation systems associated with superconducting magnets of MR systems are the main sources of ambient acoustic noise found in the MR environment. Acoustic noise produced by these subsidiary systems is considerably less than that caused by gradient magnetic fields.[10,11]

BASIC CONSIDERATIONS

2.1. Sound: A disturbance in an elastic medium resulting in an audible sensation.

2.1.1. Vibration: A disturbance in a solid elastic medium which may produce a detectable motion.[50] Human hearing is at its most sensitive around speech frequencies (200 Hz – 3.5 kHz). The full hearing range for a fit young person runs from about 20 Hz (20 cycles per second) to almost 20 kHz (20,000 cps). However, the high frequency response falls off rapidly with age; most adults can't hear much above 8 – 10 kHz. Many industrial workers and pop music fans, etc., will have permanently damaged hearing and thus a greatly reduced hearing response (i.e. be somewhat deaf!).

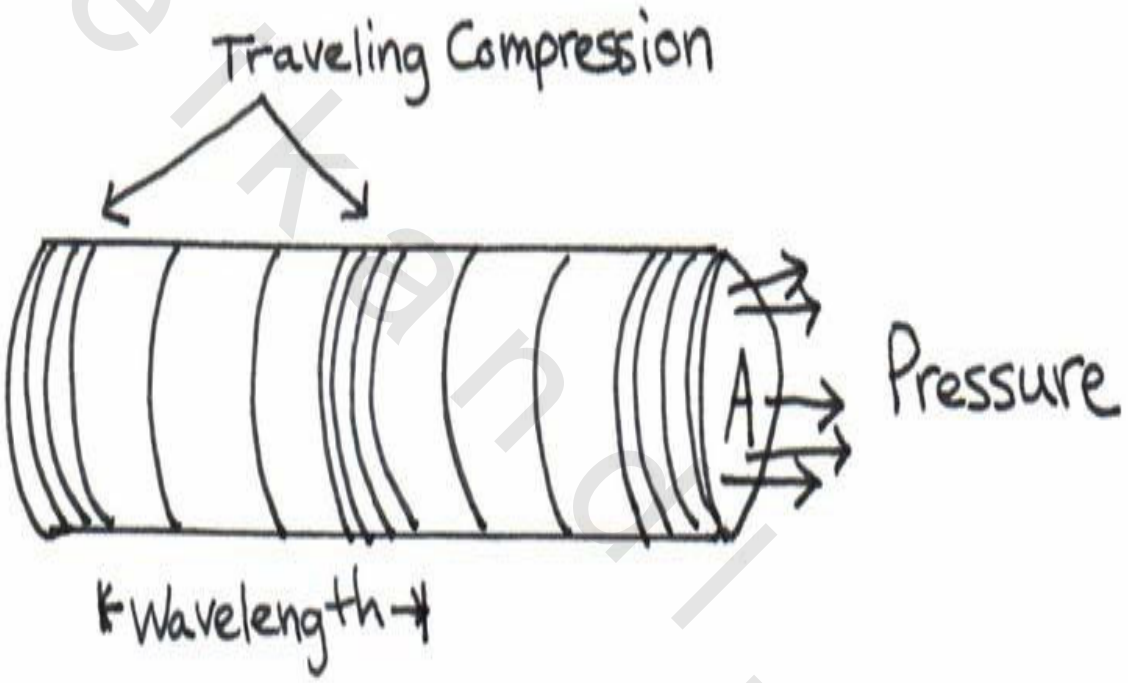


Fig.(1):Moving pressure differences.

Energy is carried by sound waves in the form of moving pressure differences. It is important to note that molecules of the medium do not travel the length of the medium with the energy; they transmit the energy by vibrating. Think of the molecules as a line of people passing along slices of birthday cake at a party. While the people (the medium) move slightly to do the passing, it is the cake (the energy) that is carried across the room. For a more accurate analogy of how sound waves propagate, imagine that the medium acts as a slinky.[51]

$$P = z\,v \qquad (1)$$

Where **P** is the instantaneous pressure as the sound wave passes by, and **v** is the instantaneous velocity of the atoms driven into oscillation by the pressure. The magnitude of **P** is directly related to magnitude of the velocity **v** of the atoms in the neighboring layer.

One might expect that lighter atoms/molecules might achieve greater velocities **v** when pushed but the same pressure. Hence the constant **z**, which is known as the impedance, must be related to inertia (mass) of the medium. In fact, it can be shown to be the product of the density of the medium, **ρ**, the speed of the sound wave, **c**, and the area affected sound, A.

$$z = \rho\, c\, A \qquad (2)$$

The concept of impedance is central toward understanding what fraction of sound gets transmitted across the eardrum and into the brain.(51)

Usually, the reference level is taken to be the threshold of sound, 10^{-16} W/cm^2. Accordingly, the number of bells for a sound with intensity I relative to the reference level is log10 ($I/10^{-16}$). Often in acoustics, the bell scale is too coarse to quantify loudness. For this reason, a finer unit is used—the decibel—where 1 bell = 10 decibels. Therefore the sound intensity level in decibels is quantified by the formula.(51)

$$\text{dB level} = 10 \log_{10} (I/10^{-16}) \qquad (3)$$

The bel is named for Alexander Graham Bell, and ten decibels equal one bell. (52)It should be noted that the decibel scale is also used for characterizing changes relative to some arbitrary initial level, i.e. something other than the threshold of hearing. For example, if the sound intensity level is known to increase from some initial level to a final level that is 1000 larger, then one can say that the intensity level increased by;(51)

$$\text{dB change} = 10 \log10 (I_{final}/I_{initial}) \qquad (4)$$

$$= 10 \text{ Log10 } (1000)$$

$$= 30 \text{ dB}$$

2.1.2. **Decibels**: The basic unit of level in acoustics is the "decibel" (abbreviated dB). In acoustics, the term "level" is used to designate that the quantity is referred to some reference value, which is either stated or implied. The decibel (dB), as used in acoustics, is a unit expressing the ratio of two quantities that are proportional to power. The decibel level is equal to 10 times the common logarithm of the power ratio; (50)

$$\text{dB} = 10 \log P1/P2 \qquad (5)$$

In this equation P_2 is the absolute value of the power under evaluation and P_1 is an absolute value of a power reference quantity with the same units. If the power P_1 is the accepted standard reference value, the decibels are standardized to that reference value. In acoustics, the decibel is used to quantify sound pressure levels that people hear, sound power levels radiated by sound sources, the sound transmission loss through a wall, and in other uses, such as simply "a noise reduction of 15 dB" (a reduction relative to the original sound level condition). (50)

2.1.3.Sound Waves: Sound waves are very small pressure oscillations that travel through most all solids and fluids which includes air. Sound is typically generated by vibratory or oscillatory motion from a machine, loudspeaker or fluid flow past an object or other physical processes that involve some motion. (52)

2.2. Frequency: Frequency is analogous to "pitch." The normal frequency range of hearing for most people extends from a low frequency of about 20 to 50 Hz (a "rumbling" sound) up to a high frequency of about 10,000 to 15,000 Hz (a "hissy" sound) or even higher for some people. (50)

At lower and higher frequencies than the speech range, human hearing is not very sensitive.This is demonstrated in that some ICE (In Car Entertainment) devices, stereo stacks, etc have a "Loudness" control in order to attempt to overcome this problem (Fletcher-Munson effect). Below 20 Hz, sound is referred to as Infrasound, as it is really sensed as a vibration rather than heard by the ear. (53)

Symptoms of acoustic neuroma are highly variable and include unilateral high-frequency sensor neural hearing loss, tinnitus, dysequilibrium, pressure in the ear, otalgia, and occasionally vertigo, which result from pressure exerted by the tumor upon the cochlear and vestibular portions of the eighth cranial nerve.(54,55)

2.2.1. Frequency Ranges:

2.2.2. **Ultrasound**: Is above the range of human hearing. Above 20,000 Hz. Dog whistles are in this category. Dogs can hear sounds at these frequency levels. In addition, studies on unborn children are studied via ultrasonic waves that are converted into real-time images.

2.2.3. Normal Hearing Range: The human ear begins to detect sounds at around 20 Hz. It can capture sounds up to20,000 Hz.Hearing is most acute at the mid- range level, 1,000 to 10,000 Hz. Human speech is mainly in the 1,000 to 4,000 Hz range.

2.2.4. Low Frequency: This range is about 500 Hz and lower. Infrasonic sounds are included in the lower end of this category.(56) The following figure(2) gives an idea of typical sound levels. These give a general idea of the quantitative sound level you may associate with a familiar environment. Sound levels in excess of 70 dB are generally associated with commercial, manufacturing and industrial facilities. (52)

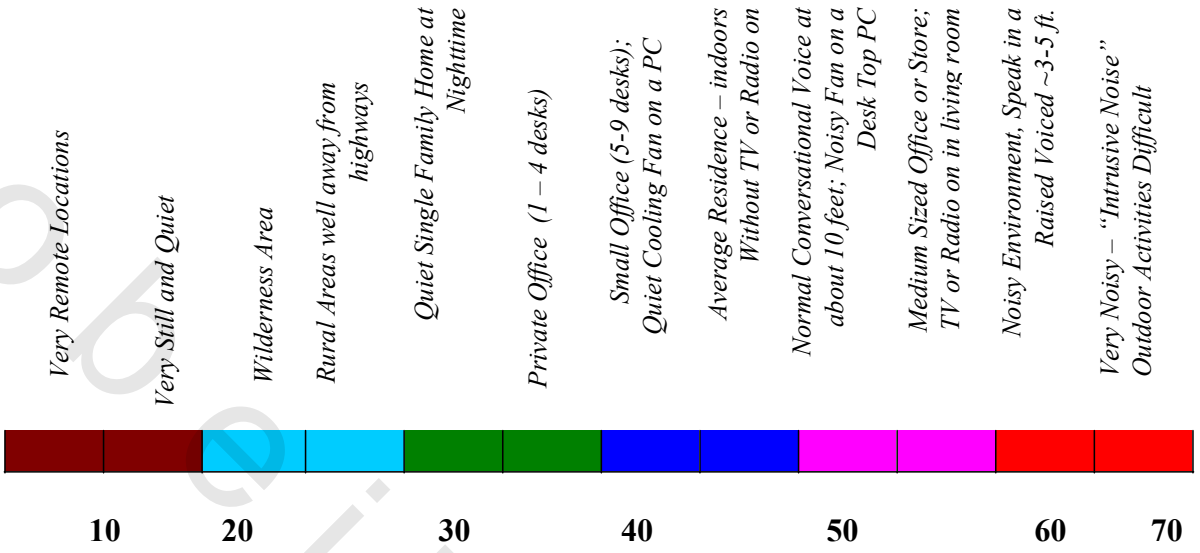


Fig.(2): Typical Range of Sound Levels, Decibels

It is well known that the MRI acoustic noise generated during imaging is very loud. In 1989,[57] *Hurwitz, et. al.* (1) measured the sound pressure level (SPL) at the magnet isocenter and reported levels between 82 and 93 dBA for static magnetic field strengths of 0.35 to 1.5 T. [57]

2.3. Sound Pressure and Sound Power

There are two parameters of sound that are used: sound pressure level ($\mathbf{L_p}$) and sound power level($\mathbf{L_w}$). Sound pressure is what is heard and measured with a sound meter at some location relative to the device being measured. Sound power is the acoustical power (watts) emitted by the device. An analogy for understanding these parameters is the light bulb. An incandescent light bulb or lamp is rated in watts but emits light (lumens). If you are very close to the light it is very bright and far away it is very dim, so distance from the lamp affects its brightness but regardless its wattage is the same. Sound behaves the same way, the farther away from a device the lower the sound pressure level but the sound power level is the same.[52]

$$L_w = 10 \log \frac{P}{P_{ref}}$$

Where P is the absolute level of the sound power and P_{ref} is the reference power. Unless otherwise stated the power, P, is the effective root mean square (rms) sound power.[50]

Sound power: Is the acoustical power (watts) emitted by the device.

Sound pressure: Is what is heard and measured with a sound meter at some location relative to the device being measured. [52]

$$L_p = 10 \log \left[\left(\frac{p}{p_{ref}} \right)^2 \right]$$

The physical relationship between sound power and sound pressure has the following basic form,

$$L_W = L_p + 10 \text{ Log (A)} \quad \text{dB re: 1 pico-watt} \qquad (6)$$

Where the "A" term describes the area over which sound pressure levels (L_p) were measured which is influenced by the size of the source of noise (machine). By examining the importance of defining the measurement area which includes the precise location of microphones, defining the surface surrounding the source of noise. Sound power is critical to know as it is used in modeling and calculating sound propagation as given by the form;

$$L_p = L_W - 10 \text{ Log (A)} \quad \text{dB re: 20 micro-pascals} \qquad (7)$$

This is very simplified but is used to show that the sound level at the receiver (L_p) is dependent upon "A" (distance or area over which the sound travels) and the sound power level (L_W).By knowing the sound power level the sound level at any location can be calculated. [52]

2.4. Sound Measurement:

Sound analyzers are used to measure sound and process the sound measurement to identify the frequencies and their respective amplitudes. This type of measurement is critically important in noise control as it is necessary to know what frequency or frequencies need mitigation. Now,machines and equipment produce sound at many frequencies, dozens of frequencies. This makes it very challenging to design noise control treatments. To help simplify this process, sound is measured across a set range or series of frequencies that are grouped together in bands. [52]

2.5. Acoustical Spectra:

When a noise problem occurs it is important to identify the cause and measure the source of noise.When designing noise control equipment you need to identify the frequencies and generally the type of problem will dictate the type of measurements. [52] The importance of making narrow band frequency measurements to identify the exact frequencies .The term, narrowband refers to any type of frequency analysis that uses a relatively small frequency bandwidth, from fractions of a Hertz to several Hertz. [52]

2.5.1. Measures of noise:

Noise is defined in terms of frequency spectrum (in Hz), intensity (in dB), and time duration.[58] Some noises are composed of many frequencies, whereas some noises contain only a few frequencies. [56]Exposure to high- intensity/low-frequency sound and infrasound can lead to the National Campaign for Hearing Health's Toxic Noise Guidelines (exposure times and decibel levels that cause hearing loss).[59]

2.6. Sound Transmission in the normal ears:

Sound travels across airwaves to the outer ear and then through the ear canal to the eardrum, which moves back and forth very rapidly in the middle ear. The eardrum and the little bones of hearing then vibrate to cause movement of the inner ear bathing the hearing nerve endings in the cochlea.This wave like movement of the inner ear fluids activate hearing nerve endings to create electrical signals in the nerve. The hearing centers in the brain then receive the electrical signal of the stimulated hearing nerve to perceive sound. The inner ear, hearing nerve, and brain code this sound energy to hear sounds and clearly understand speech show Figure (3). [60]

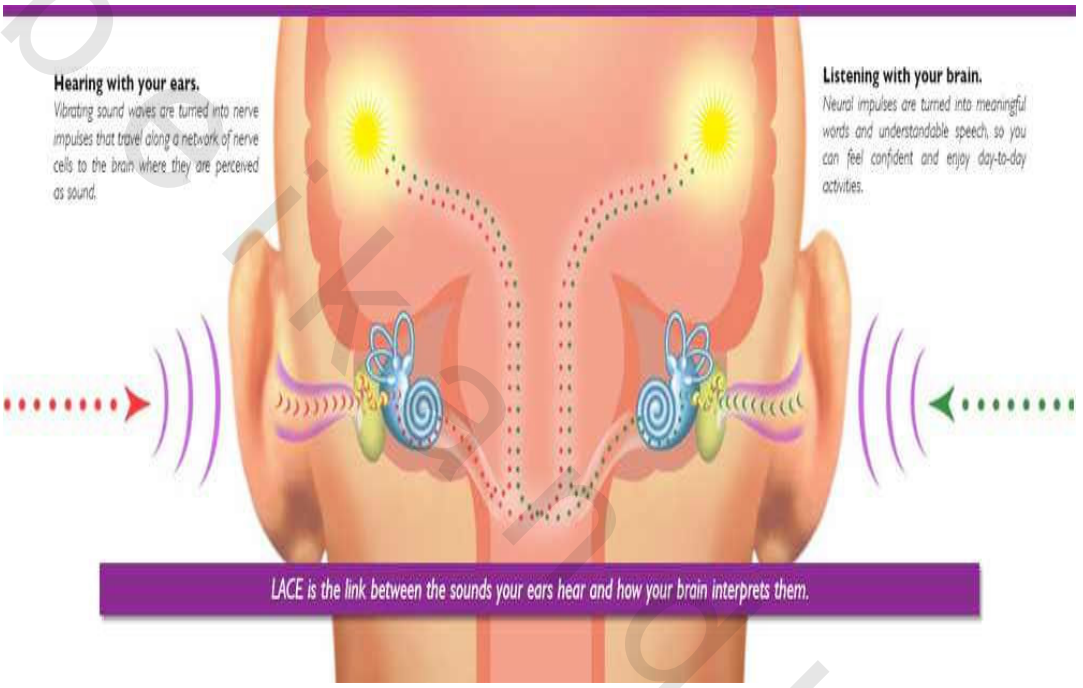


Fig.(3):Lace is the link between ears and brain.

2.7. The function of the ear is to gather, transmit, and perceive sounds from the environment. This involves three stages:

- **Stage 1:** ***Modification*** of the acoustic wave by the outer ear, which receives the wave and directs it to the eardrum. Sound reaches the eardrum as variations in air pressure.
- **Stage 2:** ***Conversion and amplification*** of the modified acoustic wave to a vibration of the eardrum. These vibrations are amplified by the ossicles, small bones located in the middle ear that transmit sound pressure to the inner ear. The vibrations are then transmitted as wave energy through the liquid of the inner ear (the cochlea).
- **Stage 3:** ***Transformation*** of the mechanical movement of the wave into nerve impulses that will travel to the brain, which then perceives and interprets the impulse as sound. The cilia of nerve cells in the inner ear, called hair cells, respond to the location of movement of the basilar membrane and, depending on their position in the decreasing radius of the spiral-shaped cochlea, activate the auditory nerve to transmit information that the brain can interpret as pitch and loudness. [61]

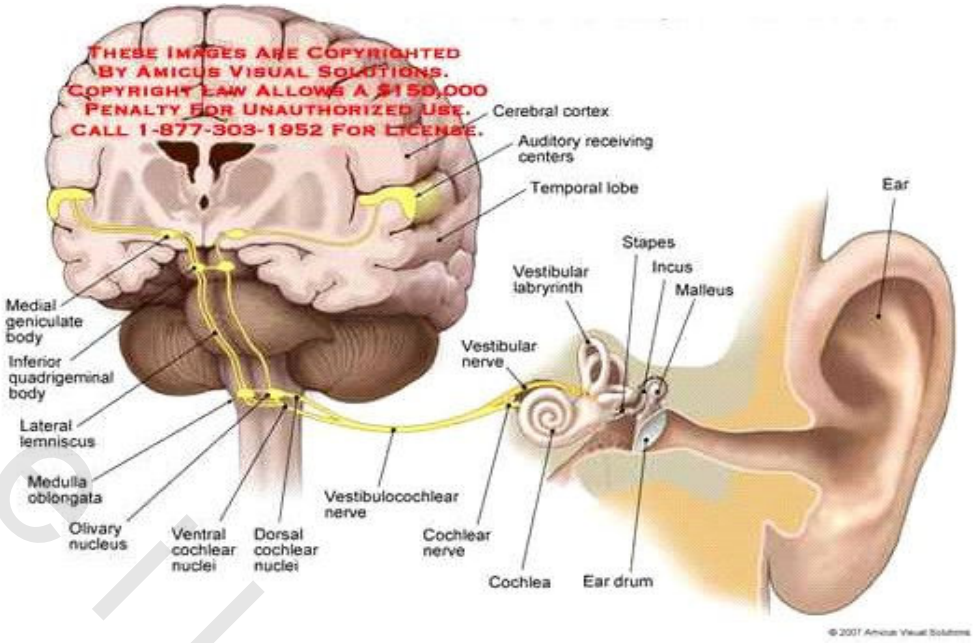


Fig.(4):Auditory Pathways to the Brain.

2.8. Auditory processing begins in the cochlea of the inner ear, where sounds are detected by sensory hair cells and then transmitted to the central nervous system by spiral ganglion neurons, which faithfully preserve the frequency, intensity, and timing of each stimulus. During the assembly of auditory circuits, spiral ganglion neurons establish precise connections that link hair cells in the cochlea to target neurons in the auditory brainstem, develop specific firing properties, and elaborate unusual synapses both in the periphery and in the CNS shown Figure (4). [62]

2.9. Physical Basis of MRI:

Magnetic resonance imaging (MRI) is an important imaging technique that is essential in modern diagnostic radiology.MRI produces morphological images of the soft tissue with high contrast, which is, for instance, not possible with computed tomography. Furthermore, MRI facilitates the study of the function of several organs. [63] MRI combines a strong magnetic field and radio frequency (RF) energy to study the distribution and behavior of hydrogen protons in fat and water of the human body. [64]

2.9.1. Multiple parameters:

2.9.1.1. T1 and T2 relaxation time:-

When a brief RF Pulse is applied with a frequency matching that of the hydrogen protons (magnetic resonance), the net magnetization direction of the protons is altered, and the protons are transiently in phase. As soon as the external electronic pulse stop, the signal begins to disappear. The signal loss is the result of two independent factors:-

1- The protons begin to return to alignment with the static, external magnetic filed (spin – lattice relaxation) time constant is called T1.

2- Interactions between nearby molecules disrupt phase coherence (spin – spin relaxation) is called T2.[65]

2.9.1.2. Repetition time (TR):-

The time from the beginning of 90° radiofrequency pulse sequence to the start of the next shown Figure (5).

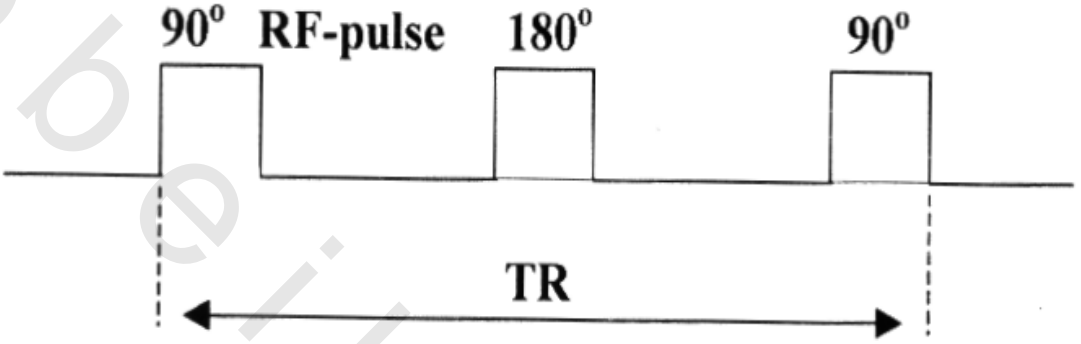


Fig.(5):Repetition time

2.9.1.3. Echo Time (ET):-

The time between the central of the excitation pulse, and the peak of the echo shown Figure (6).

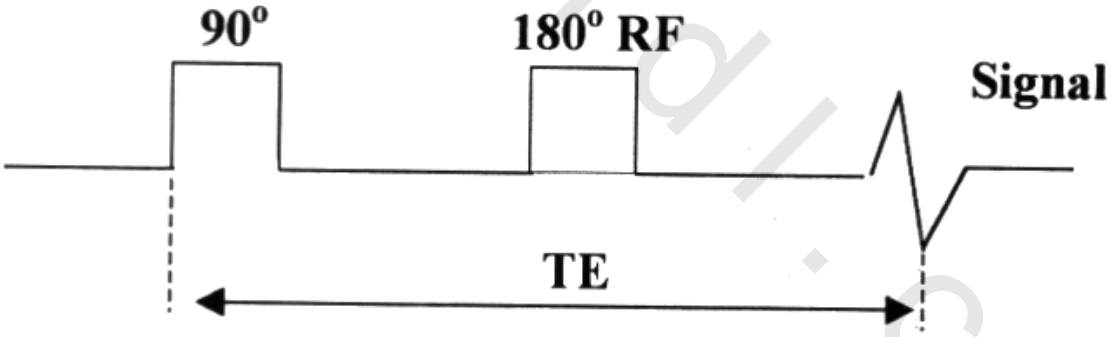


Fig.(6):Echo Time

2.9.1.4. Flip Angle:

The rotational angle of the magnetization vector produce by a RF pulse relative to the longitudinal axis of the static magnetic field.This variation in flip angle is used in gradient echo imaging to obtain the various tissue- weighted (a low flip angle typical 10 - 30 degree) produces a T2 –weighted images and a 90 degree flip angled provides T1 – Weighting shown Figure (7). [66]

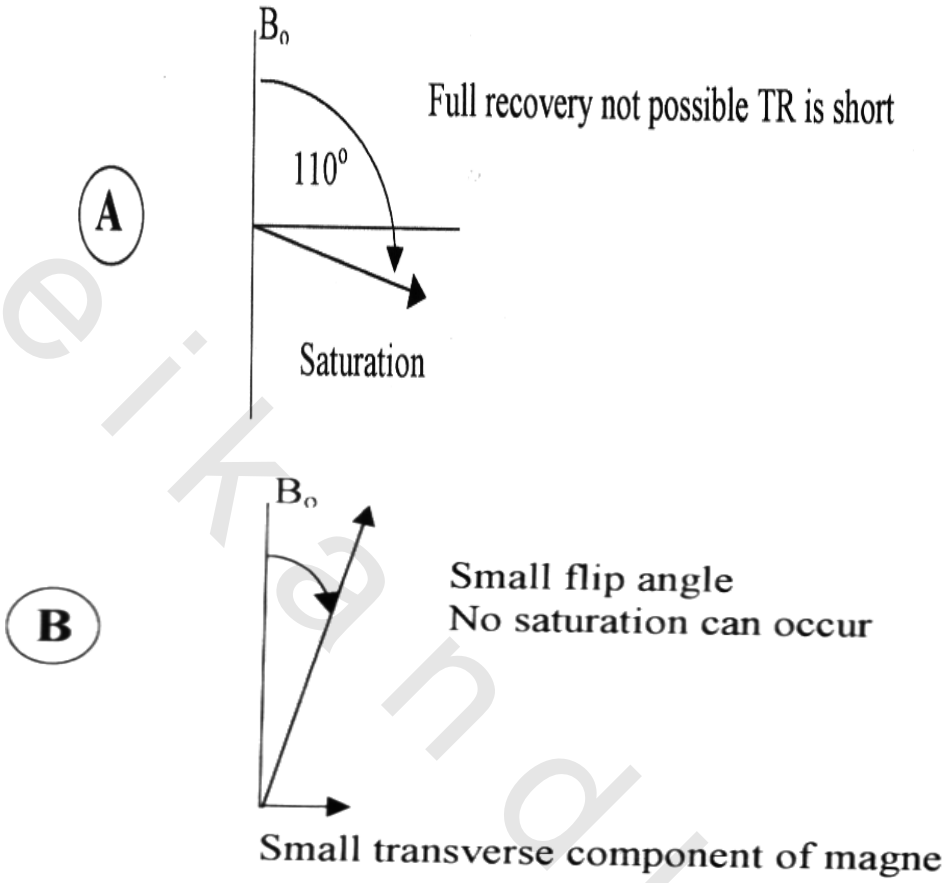


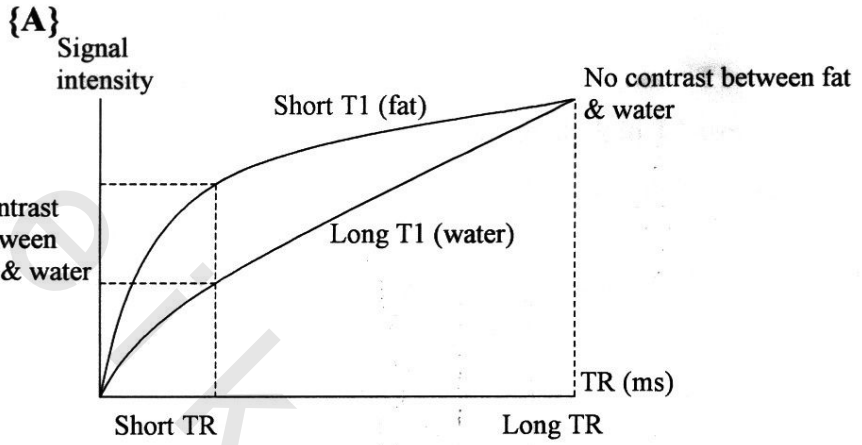
Fig.(7):A- In T1 – Weighting of gradient echo.

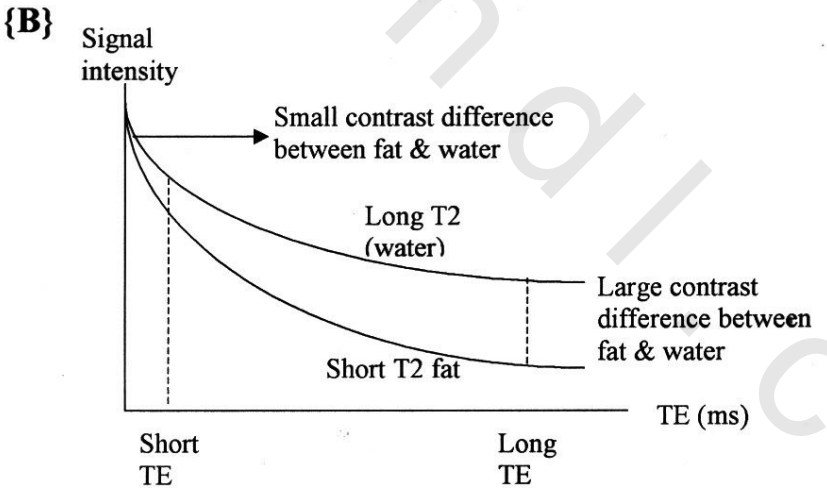
B- In T2 – Weighting of gradient echo. [67]

2.9.2. Pulse Sequences:

Most MRI Pulse sequences in clinical use:-

- Spin echo: Is after the initial signal has disappeared following a 90° (RF) pulse by the application of a refocusing 180 degree (RF) pulse. [68]
- Gradient Echo (GRE / GE): A basic sequence, which reverses gradient polarity of the spins to replace the protons and produce echoes. This allows shorter TR, thus faster scanning and flip angle less than 90°.[67]
- Spin – echo (SE) sequences with short TR and short TE produce images, in which the T1 of tissue is major determinant of signal intensity, this referred to as T1 – weighted images (T1WIs). Long TR and long TE result in images weighted heavily by the T2 of Tissue, or T 2 – Weighted images (T2WIs) shown Figure (8). [68]





In curve- **{A}** T1 differences between fat and water.

{B} T2 differences between fat water.

2.9.3. Tissue characteristic on MRI:

Fat has a short T1 and appears very bright on T1 –Weighted images, fat has lower signal and appears dark in T2 – Weighted. Water has appears relativity dark on T1 –

Weighted images and very bright on T2- weighted images. Cerebrospinal fluid CSF and vitreous humor for example, should be very bright on long TR/ long TE SE images. More importantly, edema, which is present with many pathological processes in the brain and spine, is also bright. Normal white matter is brighter than gray matter on TIWI and darker on T2WI.[65]

Advantage:

1. Lack of ionizing radiation.
2. Superior soft tissue contrast.
3. Direct multiplaner capabilities.
4. Non invasive, totally .[69]
5. MRI "invisibility" of bone is beneficial in evaluating area such as the brainstem that are obscured by CT Scanne. [65]
6. MRI appearance of blood is complex without using contrast.
7. MRI is very sensitive to bone marrow pathology.
8. No bone or air artifact.
9. Can easily distinguish lymph node from large flowing vessels with no signal.

Disadvantage:-

1. Less accurate in detection of calcified lesion.
2. Not recommended for patients with intracerebral aneurysm clips.
3. Not recommended for patients with cardiac pacemaker.
4. Metallic foreign bodies.
5. Shell or bullet injury.
6. First and second trimester pregnancy.
7. Cochlear implants.
8. Some artifacts such as aliasing, motion, partial volume effects.[70]

2.10. Dielectric Properties of Tissues:

Radio – Frequency and microwave dielectric properties of biological materials have been of interest in connection with high –frequency and microwave dielectric heating, absorption of electromagnetic energy by living systems, and for nondestructive measurement of nonelectrical properties such as moisture content of agricultural products.

These applications, including health hazards of energy absorption, medical diagnostics, and electromagnetic heating of tissues for medical purposes have spurred research on determining dielectric properties of such materials. There has been much less concentration on studies of low – frequency properties of biological materials. However, the behavior of materials exposed to low – frequency electromagnetic fields, and a better understanding of

These phenomena, may open up new application and potentially useful measurements of important characteristics in the future. Recent studies, related to material impedance and ion

Conduction through artificial membranes,[71] have opened an opportunity to study the low frequency properties. With increasing interest in biological engineering opportunities, provide some basic background for those interested in pursuing such studies.

Dielectric properties (electrical properties) of biological tissues have been of interest for many years. Information about tissue structure and compositions, for example, water content of presence of a tumor, might be obtained by measuring the dielectric properties of the tissues. The understanding of interactions between electromagnetic energy and biological tissues must be based upon the knowledge of electrical properties of the tissues. This has many practicals application in agriculture, food engineering, and biomedical engineering.

Dielectric properties of biological tissues are frequency dependent or dispersive. A significant change in dielectric properties over a frequency range, by convention, is called a dielectric dispersion. Although the dielectric properties of the tissues vary greatly form tissue to tissue, their typical behavior is characterized by three distinctly large dielectric dispersions, often referred to as α-, β- and γ - dispersions, [72] as shown in Fig.(9) the α-dispersions usually occurs below a few KHz The β- dispersions in the frequency region from tens of kHz to tens of MHz, and the γ - dispersions in the microwave frequency region.

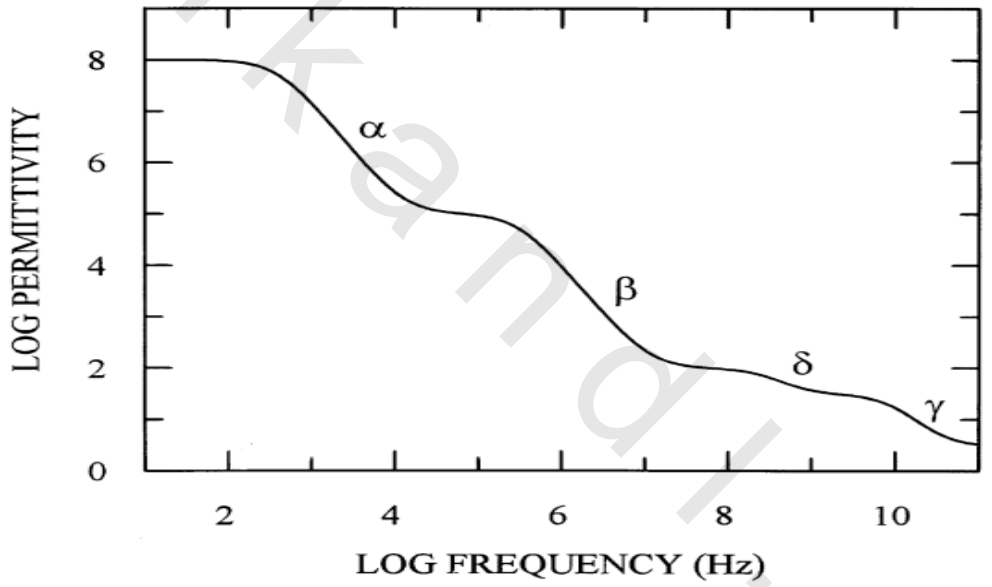


Fig.(9): Typical frequency dependence of the dielectric constant of biological tissues. A measurement of muscular tissue.

The γ - dispersions, arising mainly from polarization due to reorientation of water molecules, has been well studied and has found many applications in different areas.

Heterogeneous structure and composition and ionic activates inside the tissues dominate the low – frequency dielectric behavior of the tissues. The β- dispersion is well known to arise principally from interfacial polarization (Maxwell – Wagner effect) of biological membrane systems which act as barriers to the flow of ions between the intra and extra cellular media this was observed mainly by studying blood tissues (erythrocyte suspension) other contributions to the β- dispersion come from the polarization of protein and other organic macromolecules.

Dielectric studies of biological or any other electrolyte systems below a few kHz were very difficult, mainly because electrode polarization at these frequencies is significant. Partly for this reason, the mechanism of the dispersion of biological tissues has not been well understood. It is believed to be associated with a counter ion layer (electrical double layer) polarization in the tissues. Colloidal particle mechanisms have been well studied and should be applicable to tissues due to the presence of many macromolecules, subcellular particles, and cells in the tissues. Another mechanism associated with membrane permeability (ion passage in tissue) was recently investigated. [73]

Dielectric properties of a material basically reflect the electric charge movement inside the material in response to an external electric field. For example, dc conductivity of the material represents its free charge movement forced by the external field. Dielectric response of biological materials is always frequency dependent. A linear means that the dielectric properties are independent of the external field strength, which is true when the external electric field is not very strong. Assuming a harmonic field E is applied to the material, a current density J inside the material will be induced:

$$J = \sigma_s E + j\omega\varepsilon_0\varepsilon E = \sigma_{s\,E} + j\omega\varepsilon_0(\acute{\varepsilon} - j\,\varepsilon'') E \qquad (8)$$

Where σ_s is the dc conductivity of the material, ω is the angular frequency of the applied field, ε_0 is the permittivity of free space, ε is the relative complex permittivity of the material, $\acute{\varepsilon}$ is the dielectric constant, and ε'' is the loss factor of the material. For biological materials, ε is usually dependent upon frequency. Equation (9) can be written as:

$$J = (\sigma_s + \omega\varepsilon_0\varepsilon'') E + j\omega\varepsilon_0\acute{\varepsilon} E = \sigma E + j\omega\varepsilon_0\acute{\varepsilon} E \qquad (9)$$

Where $\boldsymbol{\sigma}$ is the conductivity of the material.From equations 3 and 4, the electrical properties of a material can be completely represented either by the dielectric constant $\boldsymbol{\acute{\varepsilon}}$, loss factor $\boldsymbol{\varepsilon''}$, and dc conductivity $\boldsymbol{\sigma_s}$, or by the dielectric constant $\boldsymbol{\acute{\varepsilon}}$ and conductivity σ. The two representations are related by

$$\sigma = \sigma_s + \omega\varepsilon_0\,\varepsilon'' \qquad (10)$$

For biological materials, $\boldsymbol{\sigma_s}$ is mainly due to ionic conduction; whereas, $\boldsymbol{\omega\varepsilon_0\,\varepsilon''}$ results from dielectric relaxation. A common circuit representation is shown in Fig.(10).

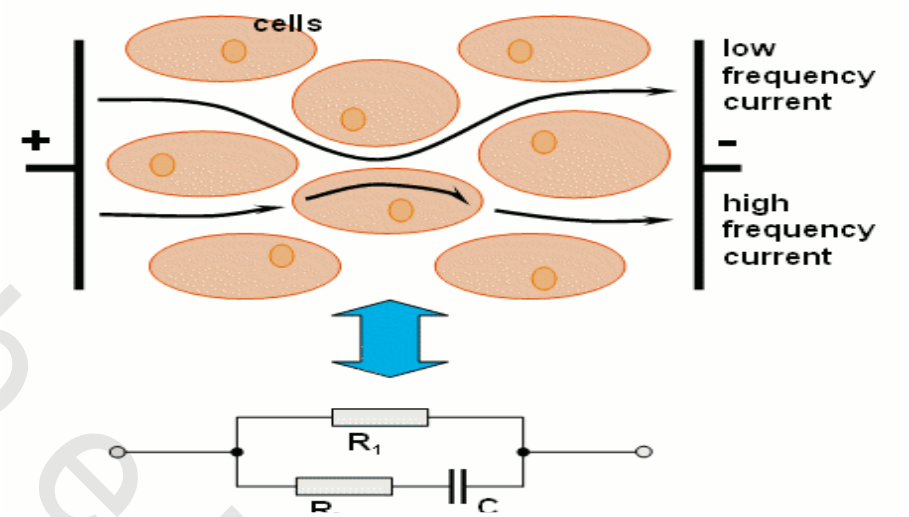


Fig (10): Sample holder of ideal parallel plates; (b) frequency dependent, measured circuit model, in which C is capacitance and G is conductance.

2.10.1. Dielectric relaxation: [74]

Polar molecules in materials will reorient under the influence of an external electric field, thus contributing to the polarization and exhibiting a phenomenon called dielectric relaxation. Free charges inside a heterogeneous material can be blocked by interfaces inside the material, also causing dielectric relaxation. Dielectric relaxation is always a frequency-dependent process. In accordance with the frequency dependence, dielectric properties of a material are characterized by relaxation time constants. A single-time-constant response is described by the debye equation:

$$\varepsilon = \varepsilon_\infty + (\varepsilon s - \varepsilon_\infty) /(1 + j\omega\tau) \qquad (11)$$

Where ε_∞ is the dielectric constant at frequencies much higher than $1/ (2\pi\tau)$, ε_s is the static, or very low frequency, dielectric constant and τ is the relaxation time.

2.10.2. Mechanisms of dispersion

The permittivity ε and conductivity σ of a material are, respectively, the dipole and current densities induced in response to an applied electric field of unit amplitude. The significance of these quantities can be illustrated by considering and ideal parallel-plate capacitor, whose plates have surface area A and separation d. the capacitance C and conductance G of the capacitor are then:

$$C = (\varepsilon\varepsilon.A)/d \qquad (12)$$

$$G = (\sigma A)/d \qquad (14)$$

For tissues, both ε and σ are strong functions of frequency Fig.(11). This frequency dependence (dispersion) arises from several mechanisms. These mechanisms are discussed, with reference to simple biophysical models, in foster and schwan[73].For a typical soft tissue, different mechanisms dominate at different frequency ranges:

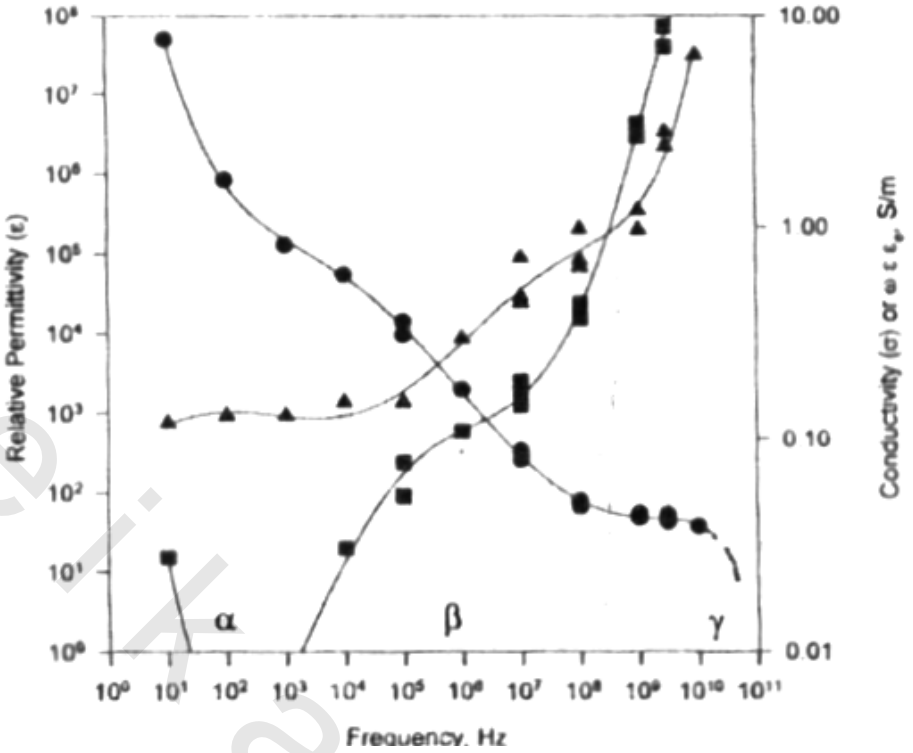


Fig (11): Relation between relative permittivity, conductivity and frequency.

1. At low frequencies (typically below several hundred kilohertz), the conductivity of the tissue is dominated by conduction in the electrolytes in the extracellular space. The bulk conductivity of the tissue is then a sensitive function of the volume fraction of extracellular space and the conductivity of the extracellular medium.
2. At low frequencies, the tissue exhibits a dispersion (the alpha dispersion), centered in the low kilohertz range, due to several physical processes.These include polarization of counter ions near charged surfaces in the tissue and possibly the polarization of membrane-bound structures in the tissue.
3. At frequencies below the alpha dispersion, the relative permittivity of tissue reaches very high values, in the tens of millions. The alpha dispersion is very apparent in the permittivity but hardly noticeable in the conductivity of the tissue.
4. At radiofrequencies, the tissue exhibits a dispersion (the beta dispersion), centered in the range 0.1 to 10 MHz, due to the charging of cell membranes through the cellular and extracellular media.Above the beta dispersion, the cell membranes have negligible impedance, and the current passes through both the extracellular and intra- cellular media. The beta dispersion is apparent in both the permittivity and conductivity of the tissue.
5. At microwave frequencies (above 1 GHz), the tissue exhibits a dispersion (the gamma dispersion) due to rotational relaxation of tissue water. This dispersion is centered at 20 GHz and is the same as that found in pure liquid water.

In addition to these three major dispersions, other smaller dispersions occur due to rotational relaxation of bound water or tissue proteins, charging of membranes of

intracellular organelles, and other effects. These dispersions overlap in frequency and lead to a broad and often featureless dielectric dispersion in tissue. [74]

2.11. Oxidative stress

Oxidative stress, defined as an imbalance between oxidants and antioxidants in favor of the former, results in many biochemical changes and also is an important factor contributing to several human chronic conditions such as atherosclerosis, cardiovascular diseases, neurodegenerative disorders, and cancer; it is also associated with the aging process.[75] However, severe oxidative stress can cause cell injury and death.[76] Free-radical-induced cell death can proceed as necrosis or apoptosis, and "anti-apoptosis genes" in certain cells appear to encode free-radical scavengers.[77]

Oxidative stress, a condition of an imbalance between the oxidant and antioxidant defense systems, is an important factor in the pathogenesis of neurological disorders because the nervous system has a high content of polyunsaturated membrane lipids. [78]

The stressors can also induce myocardial ischemia and ventricular arrhythmias in patients with coronary artery diseases [79], which associate with oxidative stress. It is thus suggested that psychological stress is associated with increased oxidant production and oxidative damage, and thus long-term exposure to psychological stressors may enhance the risk of many diseases. [80]

In general, harmful effects of reactive oxygen species on the cell are most often:

1. Damage of DNA.
2. Oxidations of polyunsaturated fatty acids in lipids (lipid peroxidation).
3. Oxidations of amino acids in proteins.
4. Oxidatively inactivate specific enzymes by oxidation of co-factors. [81]

During noise exposure, the electron transport chain of the mitochondria uses large amounts of oxygen, which can then create large amounts of superoxide generated as an unwanted by product. Excessive production of superoxide can then generate higher levels of other reactive oxygen species (ROS) such as hydrogen peroxide and hydroxyl radical through Fenton reaction, or react with nitric oxide to generate reactive nitrogen species (RNS) such as peroxynitrite.[82] Free radicals are capable of damaging DNA, breaking down lipid and protein molecules, and triggering cell death, all of which can contribute to the hair cell lesion and loss of function seen after noise (Henderson et al., 2006).[82]

Environmental noise is a stressor and acute exposure to loud noise has been shown to affect a number of physiological, metabolic and immunological functions *(Babisch 2003; Ising and Kruppa 2004; Spreng 2000a)*[83,84,85].

2.12. Malondialdehyde (MDA): is an endogenous genotoxic product of enzymatic and oxygen radical-induced lipid peroxidation whose adducts are known to exist in DNA isolated from healthy human beings.[86] In the last 20 years, MDA has been recognized as a relevant lipid peroxidation marker and as such, the measurement of MDA levels in

biological samples from subjects affected by several diseases has been widely utilized[87].Serum level of MDA is used as a marker of oxidative status. MDA levels are related to the formation of oxygen-free radicals, which deactivate nitric oxide (NO) and also inhibit NO production in the endothelial vascular bed. [88]

Increasing evidence also suggests that continuous exposure to loud noise releases an excessive amount of free oxygen radicals, which induce tissue damage.[89] Increase production of free radicals leads to increase producing lipid peroxidation end products such as (MDA) (*Derekoy FS, et al., 2001*). [90]

2.13. Superoxide dismutase (SOD) (SOD: EC 1.15.1.1):

Three forms of superoxide dismutase are present in humans shown in Fig.(12), in all other mammals, and most chordates. SOD1 is located in the cytoplasm, SOD2 in the mitochondria, and SOD3 is extracellular. The first is a dimer (consists of two units), whereas the others are tetramers (four subunits). SOD1 and SOD3 contain copper and zinc, whereas SOD2, the mitochondrial enzyme, has manganese in its reactive centre. [91,92]

SOD is one of the main reactive oxygen species scavenging in the cell. As a consequence, SOD serves a key antioxidant role. The physiological importance of SODs is illustrated by the severe pathologies evident in mice genetically engineered to lack these enzymes. [93] Simply stated, SOD out-competes damaging reactions of superoxide thus protecting the cell from superoxide toxicity. The reaction of SOD with non-radicals is spin-forbidden. In biological systems, this means that its main reactions with itself (dismutation) or with another biological radical such as nitric oxide (NO) or with a transition-series metal. The superoxide anion radical (O_2^-) spontaneously dismutase to O_2 and hydrogen peroxide (H_2O_2) quite rapidly (~10^5 $M^{-1}s^{-1}$ at pH 7). SOD is necessary because SOD reacts with sensitive and critical cellular targets. [94]

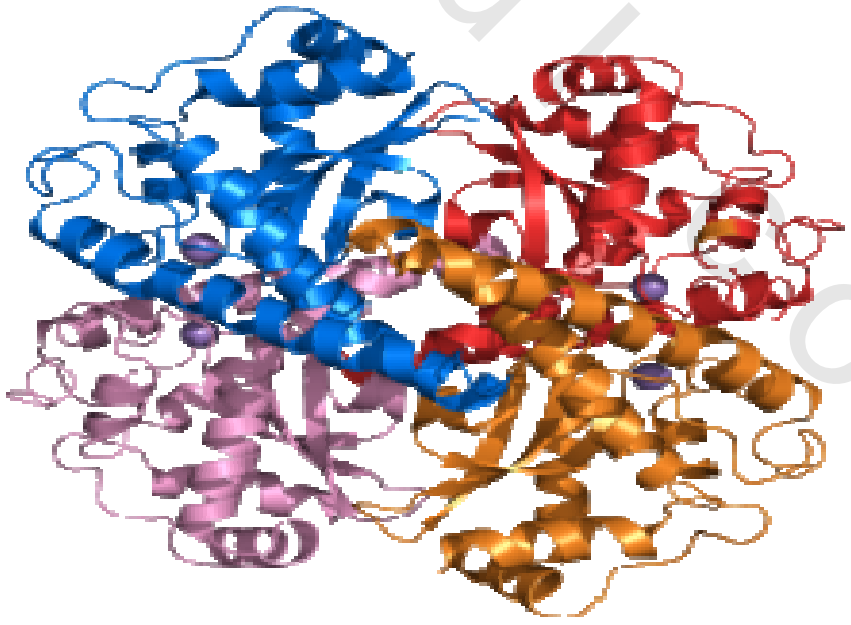


Fig (12): Structure of a human Mn superoxide dismutase 2 tetramer.

A decrease in SOD levels in a particular area of the brain may indicate that it is more sensitive to noise.[95]Acute noise stress significantly increases the levels of superoxide dismutase and lipid peroxidation (LPO). The noise induced alterations in free radicals may be assumed to serve as a linkage between the environmental noise and the manifestation of multifactorial diseases attributed to noise exposure. [86]

2.14. Glucose:

Animal experiments demonstrated that noise can induced alterations in the sensitivity of cellular cortisol receptors by increase of heat-shock proteins, and ultra-structural modifications in heart tissue and adrenal gland. An elevation in cortisol levels have been detected in humans and animals that exposed to aircraft noise or road traffic noise *(Spreng, 2000 b).* [96]

The adrenal gland, producing cortisol adrenocorticotropic hormone (controlled by ACTH) and androgens and it is lead to stimulation of hypothalamic-pituitary- adrenal HPA-axis and enhance insulin resistance by inhibition of transport and utilization of glucose with increasing levels of glucose in blood. [96]

When the body interprets an action as a stress, the director of the stress response is the brain center known as the hypothalamus. And stress is any action that causes an excess of glucocorticoid hormone release from the adrenal glands. The area involved in the outer layer of the gland is the adrenal cortex; that involved in the inner layer is the adrenal medulla shown in Fig.(13). [97]

Short-Term Stress Response:

1. Increased heart rate
2. Increased blood pressure
3. Liver converts glycogen to glucose and releases glucose to blood.
4. Dilation of bronchioles.
5. Changes in blood flow patterns leading to increased alertness, decreased digestive system activity, and reduced urine output.
6. Increased metabolic rate. [98]

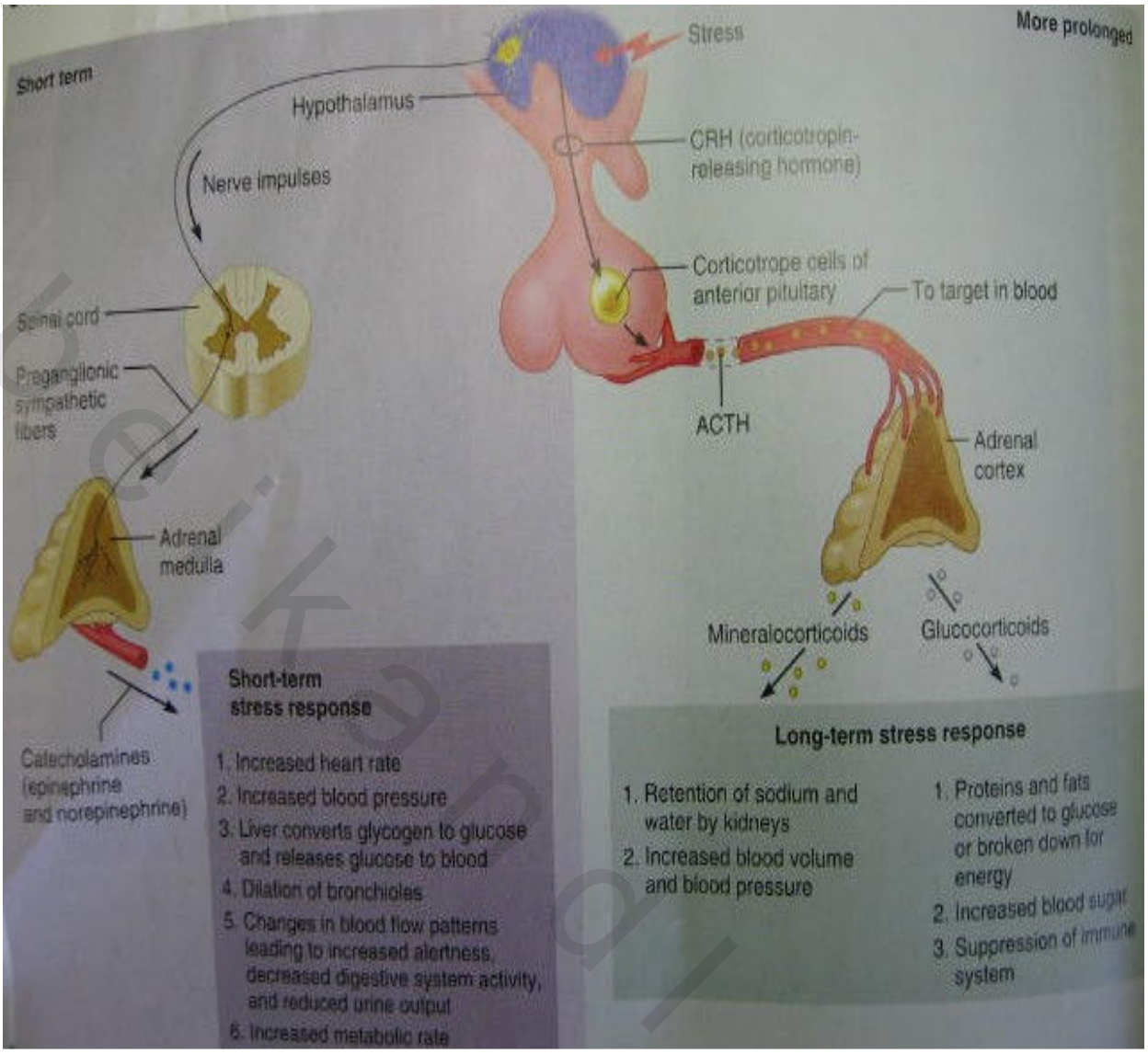


Fig.(13): Human Anatomy & Physiology Note: On the top left–hand chart designating that response hypothalamus is "Short Term stress.

2.15. Complete blood count (CBC):

A complete blood count (CBC) test measures the following:

- The number of red blood cells (RBC count)
- The number of white blood cells (WBC count)
- The total amount of hemoglobin in the blood
- The fraction of the blood composed of red blood cells (hematocrit).

The CBC test also provides information about the average red blood cell size (MCV), hemoglobin amount per red blood cell (MCH), the amount of hemoglobin relative to the size of the cell (hemoglobin concentration) per red blood cell (MCHC) and platelet count. RBCs transport hemoglobin which, in turn, carries oxygen. The amount of oxygen

received by body tissues depends on the amount and function of RBCs and hemoglobin. WBCs are mediators of inflammation and the immune response. There are various types of WBCs that normally appear in the blood: Neutrophils ,neutrophils, monocytes ,eosinophil and basophils.[99]

White blood cells count is an important hematological parameter. White blood cells help to defend the body against infectious diseases and foreign materials as a part of immune system *(Dacie and Lewis, 1995).* [99] Elevated white blood cells count indicates infection, inflammation or some form of leukemia. Variation in the number of different types of white blood cells help to identify the effect of medication or some chemical *(McPherson and Pincus, 2007)* [100].Stress can also activate the platelets in the blood *(Lederbogen et al., 2009)*[101].Physiological studies have shown that stress could alter the blood parameters in healthy individuals. [102]