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Early Diagnosis of Pre-Osteoarthritis by Phonoarthrography using Artificial Intelligence

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Abstract: - The significance of this examination is to get a legitimate conclusion on the significance of joint sounds in early detection of Osteoarthritis. Auscultation is one of the most past strategies for determination. It has been broadly applied in looking at different organs of the physical structure, yet its utilization for considering joint-sounds is as yet an unfamiliar district of request. On that point is that sound is important to both the rheumatologists and orthopaedic specialists who diagnose and prognose when the knee is influenced with osteoarthritis. As sound generated by joint surfaces were considered as a backup to osteoarthritis where recording it appeared to be fascinating and conceivable to

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many research labourers. Another examining framework has been created and its clinical application has been finished. The joint-sounds are inspected with a restricted band range analyser and an information processor. The range of foundation impedance is then deducted from the direct arrived at the midpoint of range to acquire the phonoarthrography. Our investigation uncovers that the majority of the joint sounds go in recurrence from about 1.5 kHz to 3 kHz. The noteworthiness of both higher and lower recurrence sounds relies upon a few elements like, thickness and the hardness of the articular surface and cartilage. Joint-sounds think about the difference in bone, yet additionally about something different because of degenerative joint infection. Inclusion of Artificial Intelligence in detection and processing unit can increase efficiency of obtaining accurate result. The significance of this examination is to get a legitimate conclusion on the significance of joint sounds in early detection of Osteoarthritis. Auscultation is one of the most past strategies for determination. It has been broadly applied in looking at different organs of the physical structure, yet its utilization for considering joint-sounds is as yet an unfamiliar district of request. On that point is that sound is important to both the rheumatologists and orthopaedic specialists who diagnose and prognose when the knee is influenced with osteoarthritis. As sound generated by joint surfaces were considered as a backup to osteoarthritis where recording it appeared to be fascinating and conceivable to many research labourers. Another examining framework has been created and its clinical application has been finished. The joint-sounds are inspected with a restricted band range analyser and an information processor. The range of foundation impedance is then deducted from the direct arrived at the midpoint of range to acquire the phonoarthrography. Our investigation uncovers that the majority of the joint sounds go in recurrence from about 1.5 kHz to 3 kHz. The noteworthiness of both higher and lower recurrence sounds relies upon a few elements like, thickness and the hardness of the articular surface and cartilage. Joint-sounds think about the difference in bone, yet additionally about something different because of degenerative joint infection. Inclusion of Artificial Intelligence in detection and processing unit can increase efficiency of obtaining accurate result

Keywords*:* Knee Joint, Joint sounds, Osteoarthritis, Phonoarthrography, Early detection, Artificial Intelligence, K-L Scale.

1. Introduction

Degenerative joint illness is the joint's primary regular stress, that affects most of the worldwide population. This malady occurs when the protective layers of the bone gets degenerated. The degenerative joint infection can distress any joint in our body, where mostly influences the movable joints in hands, knees, hips and back. The side effects of Osteoarthritis can be reduced ordinarily, but it is the fact that the fundamental handle cannot be modified. Remaining dynamic, keeping a sound weight and other medicines including injections may moderate movement of the malady and offer assistance progress torment and

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joint function. For a long time, clinical subjects for exploratory sedate tests have utilized a blend of analog scales for evaluating torment and joint work in symptomatic OA. These scales were incapable of determining either the substance of treatment on basic changes caused by the illness or the work of treatment in anticipating cartilage debasement. Torment scales may as it were reflect the pain relieving properties of a given intercession. And because articular cartilage lacks pain fibres, pain in OA joints probably originates from other anatomical structures, such as subchondral bone, synovium, tendons and muscles, making these assessments indirect, and therefore they do not reflect deteriorating cartilage morphology [06].

The study focuses on the evolution of sounds from the musculoskeletal system responsible for locomotion, when pointing to hear and localize loose bodies within the knee, using a stethoscope [10].Previously Auscultation was performed applying a stethoscope equipped with a rubber diaphragm where slipping and skin friction noises are prevented therefore[07].Graphically, by linking the obtained waveform to various joint position it can be sorted . Most of the joints recorded were the knees [04] and temporomandibular joint [05]. The major advantage as they are deep and shallow structures making it perfect for auscultation and recording. The second reason is that they produce sounds in case of degeneration. Then trends involved Phonoarthrography , that involved using a particular detector, amplifier, special recorder, tape, and a memory oscilloscope. Nevertheless, due to the limited memory of the oscilloscope, this method was a loser. Later on, a computerized system using sensors was used; the results obtained were consistent and were shown as the mean amplitude and frequency values [04].The purpose of our study is employing Artificial Intelligence that can increase efficiency of result accuracy.AI analyses the spectrum band waveforms and provides the level of degenerative infected joint comparing to K-L Scale and can be found detrimental in both Malady identification and level of degradation. Phonoarthrography is the broadly approved idiom to identify the medical procedures as it refers to sounds (Phono), originating from the joints (Arthro)[06]

2. Overview Of Knee Sound

Sound, a mechanical noise from a condition of equilibrium that proliferates through a flexible material medium. Defining audio is done as that which is understood by the ear, but proving lack of specificity and is restrictive. As, it doesn't apply in speaking of sounds that cannot be picked up by the ear of higher organisms like human, such as those that are far low from hearing range like the noise produced by whistle of dog and SONAR device[24].

Figure 1: Wave Nature of Sound

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By studying sound waves and their properties there are two broader classification as, transverse and longitudinal, distinguished by means of propagation. Transverse wave contains its wave particles oscillating perpendicularly. They are widely produced by electromagnetic sources. Longitudinal wave particles propagate experiencing consecutive compressions and rarefactions Sound travels as a longitudinal wave through medium like air etc .

Example of transverse wave can be like pulling thread by applying force on both end of thread and releasing which causes an oscillation in phonons [08].On the other hand Longitudinal wave is found to occur when we apply pressure to both ends of a helically wounded spring due to consecutive mechanisms of Push and Pull.

A. Knee Joint

The knee joint, distinguished as a uncomplicated hinge like structure, is on contrary one of the complex construction. The knee experiences three articulations: Between femoral condyle and second od lateral and medial articulation between tibial condyle and the next between patella and thighbone. This joint is a important location for diagnosis, with OA the predominantly found disease. Structure of Knee is formed by Femur, Tibia and Patella . that are protected by articular cartilages and other supporting ligaments found exterior and interior of knee structure. To be Added the knee joint is held up by muscles on the front , centre and backward faces of the joint. The lateral joint is protected by fibrous connective tissue[28][29]. Inside to Knee capsule, two crescent-shaped Menisci being fibro cartilagious in nature provide additional support to improving joint coherence. The Anatomy extends a feature of bursae and fatpads distributed throughout the knee to support smooth functioning of these joints. The movement of these joints in harmony can prevent degeneration of the Menisci[09] [10][11].

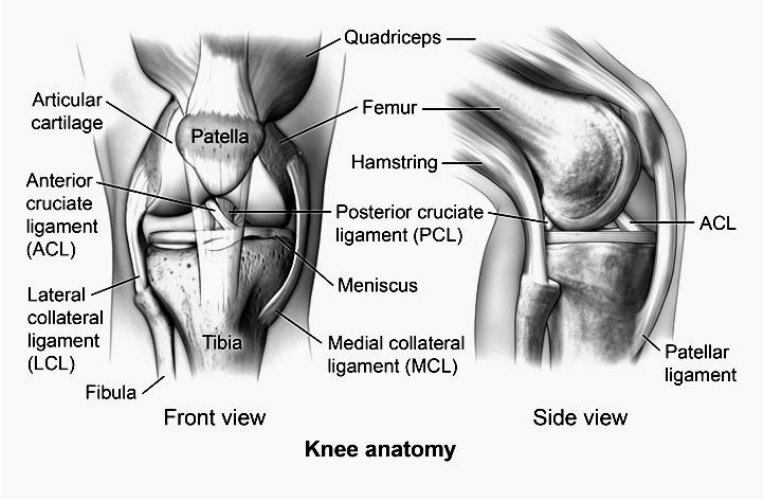

Figure 2: Cross Sectional Image of Knee Joint

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B. Cartilage

Cartilage is found in the human in many parts . It is classified as hyaline, elastic and fibrous cartilages. Hyaline cartilage is the widely found variety which is found in articular joint surfaces, nose and pulmonary organs like Bronchi and windpipe. Fibrous cartilage, termed due to its denser texture acts as a fundamental component in intervertebral discs, menisci of the knee, tendon insertions, sternoclavicular and mandibular joint and pubic symphysis. Next is Elastic Cartilage the most flexible type found in Larynx(voice box), external ear flap and Epiglottis, Hyaline cartilage. Hyaline cartilage prevalently found makes up the joint surfaces as Femur, Tibia and Patella(kneecap)which is otherwise known articular cartilage that smoothens the joint's sliding movement. On the whole Hyaline and Fibrous cartilages are encountered commonly in articulating surfaces. [12].

C. Joint Capsule and Ligaments

Knee joint is surrounded by dense fibrous capsule which is conjoined to Femur and lies above the femoral condyles and located at distant to Tibia's joint margin. The popliteus tendon exits the knee joint even before attaching on tibia as the joint capsule in deficient on the left side. However,by the iliotibial tract the capsule is reinforced extracapsular that emerges at the proximal femur and inserts at the lateral tibial condyle. Furthermore, the Lateral collateral ligament (LCL) and the medial collateral ligament (MCL) Hold on to the lateral and medial capsule respectively. The oblique popliteal ligament arises from the semi membranous tendon forms denser cruciate ligament to support the posterior joint capsule as is passes from the medial tibial condyle to the posterior femur. To boot, the arched posterior ligament hold up the posterior capsule[13].

The LCL being round and cord-like, distributed from the lateral epicondyle of the thighbone to the mid of the fibula. The MCL alternatively is a wide, flat ligament that adheres to the proximal medial tibia from the medial epicondyle of the thighbone. To attach safely to the medial meniscus the deep fibers of the MCL penetrate the joint capsule. The tibial adduction (Varus) and the tibial abduction (valgus) is prevented by LCL and MCL respectively. The MCL is found to be frail than LCL and more prone to damage and injury. The deep attachment to the medial meniscus often result in both the corollary injury of the MCL and medial meniscus.[14].

D. Menisci

The knee comprises of Arched shape menisci made of fibro cartilage found in medial and lateral joint as concentric structures like plates. They deepen the joint, volumes up the congruity at the tibiofemoral joint .Also, they contribute in absorbing shocks. Each Menisci is thick, protuberant and attached to both the joint capsule and tibial plateaus through meniscotibial ligaments .On contrary the inner edge of meniscus is feeble and delicate prone

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to injury. Preeminently , the concave feature provided evaluating the joint capability in distributing the applied load for femoral condyles [15].

E. Muscles

The knee is surrounded by several muscles supporting the articular function. The main muscle group is quadriceps that is present in front of the knee joint The knee extensor torque is generated with help of this and adheres to the tibial tuberosity through the tendon of the patella. The quadriceps are formed by such as the medialis, intermedius, lateralis vastus and the rectus femoris. The vastus medialis lies in middle of front thigh. Deep to the rectus femoris lies the vastus intermedius in front of femur. It also arises from the front and lateral part of the femoral shaft and roots to the deep part of the patella using the quadricep tendon [16].

F. Bursae

Bursae is common inflammation occurring site in knee joint that are closer to knee joint Several bursae are found close to the knee joint irrespective of presence or absence of osteoarthritis (OA). Sorted variety founded are suprapatellar, popliteal, anserine, gastrocnemius, semimembranosus, prepatellar and shallow infrapatellar bursae It is mostly found in regions between the tendons and bones to reduce frictionless movement. Synovial fluids are witnessed in the membrane which serves as a lubricant. However, providing additional stress to joint, the walls of synovial membrsne swells up as it thickens providing deformity in skin as a inflammation in area of bursa [17].

G. Propagation of Sound in Joints

Sound is a wave of phonons (sound particles) thatpropagates through medium, like air, water. Although Patella being thin produces sound in joints. The wave propagating experiences either reflection or refraction sometimes even reducing intensity. The relationship between density and force per unit area moves the Phonoarthrography sound produced. This decides the sound speed in the medium and is influenced by temperature., As tissue thickness doesn’t vary from person to person the only thing considered is intra-articular weight that varies in case of person with OA which experience swelling. So the extra synovial fluid is advised to be drawn out before diagnosis.as the medium expansion can cause disturbances in sound propagation and recording [06].

H. Knee-Noise

The knee proliferates sound during its movement and it sound is different from the sound produced by degenerated cartilage in case of OA. Synovial nodes are secluded extremely from each during joint movements that cause the sudden increase in volume in articular capsule creating negative pressure. This sudden void cannot be filled up by existing synovial fluids thus, emanating the gases dissolved in it like carbon dioxide that promotes to bubble

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formation[19].This occurring phenomenon is termed as Cavitation. In addition these cavitation in synovial joints result in generating cracking sound.

3. Methodology

A. Phonoarthrography using AI

To ensure the exclusion of generalized degenerative joint illness, plain radiographs were used to verify having their interphalangeal joints to be healthy. It's found not all knees were affected by fluid flooding and flare .The patients were provided with nonsteroidal anti-inflammatory drugs (NSAIDS), paracetamol and other local applications.[20].Patients who haven't faced any accident and trauma along with people free from medical interventions to the knee in the previous half year were recorded collecting records of various age group people ranging from 20 to 45 years and average was found to be 35.5 with following the same procedure to all the consented patients regardless of different age but with respect to sorting of gender to provide more accurate information regarding healthy cartilage that is free from degeneration. [21] [22].

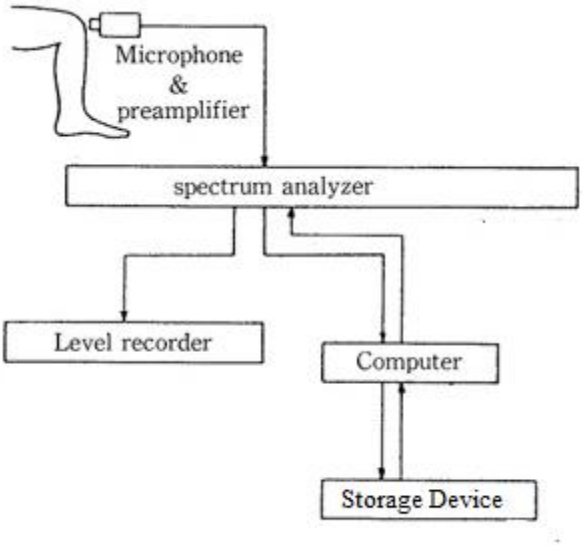

Figure 3: Block diagram of the phonoarthrography Recording set up

An alternate non-intrusive cartilage diagnosis element provides better assistance to sports management ,diagnosis and prevention of degenerative joint illness .As a whole,the sound signal from joints or articular surfaces are used to analyze the health of the cartilage.The load due to illness and physiological changes is correlated with the friction and stress in the joints which are provided in the result of cartilage health diagnosis[23]. The result obtained from diagnosis provide index fir better understanding by everyone and are useful in developing and deriving Rehabilitation Assistance ,Health program and other practices and procedures of betterment.[04][22].

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Initially an unknown sensor along with oscilloscope and recorder where uses to record joint sounds. But the major drawback of this is its inability for background noise cancellation and limited memory of oscilloscope not able to record completely the movement of flexion and expansion. Later on, a narrowband spectrum analyzer along with a computer was employed which involved in subtraction of background noise from obtained spectrum band. Sound levels were distinguished as L type(>2.5kHz) and H type(>3.5kHz).But it also didn't provide about level of degradation of the cartilage and its health also, it was found that the sound recorded where due to cartilage thickness and hardness. The came into action the method of Phonoarthrography that employed a microphone along with program fed personal computer[24][25].

First Employed Methodology:

Phonoarthrography was first recorded in year 1995 that used a microphone and personal computer(PC).It follows the following steps of procedure.

1. The examination time period was about 2 seconds each for a flexion and expansion. It was executed to be like what performed in thephysical assessment of the knee to feel the crepitus.

2. The patient was situated on a seat with the knee bent so as to fix a steady load (that of the lower limb) and to keep away from noise originating from the hip joint.

3. An account of the background noise in the room was concerned. After its investigation, a standard value for the noise is presently acquired. In the event that the device is situated in a sound-proof room(anechoic), there will be no requirement for standardization of the noise.

4. Ultrasound gel was used over the shaved patellar skin to avoid friction noises.

5. The detector was put over the substance of the kneecap or the patella in the spot fixed.

6. The signal acquired through above mentioned procedure is recorded and analyzed [26].

Recordings of sound was carried out for person in two positions while in standing and also while sitting.The result was obtained such that having greated index value during standing rather than sitting and reasoned it as cause of Weight and tension put on by the person on knees [27]. The hamstrings, biceps femoris, quadriceps femoris contribute to movement of flexion that increased the sound recorded in standing position. Furthermore, the Patella is found to expand producing large sound values which experiences the sliding friction due to the movement of articulating surfaces[22].

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B. Modern Technique

The tremendous technological advancement uses to link modern methodology to achieve phonoarthrography[28].The Knee recording followed up after hyaluronic injections with microphones placed with gap of 10mm between them was placed on knee cap. It was especially carried out for cases with end stage osteoarthritis of the knee, patellofemoral disorders and bucket-handle meniscal tears. Results varied for patients provided with injections constituting hyaluronic and steroid and observed that the sound intensity decreased after a day in case of hyaluronic and remained unchanged for steriod. Our study suggest having a strip or a cuff wrapped over the joint have inbuild sensor SoundSee -Insight with Audio AI [28]which performs the work of Audio signal processing and sends to next block with AI performing comparison of acquired with the pre-defined data set.

C. Data Acquisition

People with different age suffering knee issues were recorded and was differentiated as

1.Healthy cartilage(normal)

2.Case of Osteoarthritis(OA)[person below 18 and suffering from previous accidents were excluded]

The signals found with a sampling frequency of ≥ 44.1 kHz and down sampled to 16 kHz for subsequent processing, A micro phone was used to collect and record sounds from fixing it to Patella for person who is made to walk on treadmill until reaching maximum speed of walking (defined as the maximum pain-free speed). The achieved maximum speed achieved variesper subject ranging from 2.5 to 9 km/h.

D. Demographic Grading Data

Antero-posterior weight-bearing radiographs of both knees were held. The grading of radiographs was done by a blinded observer (M.K.). The joint space width of the medial and lateral compartments of Antero-posterior films of the knee was measured in millimeters. Knee radiographs were assessed with the Kellgren–Lawrence (K-L) grading scale.

The KL grades were paid by two independent orthopedic surgeons and recorded at three compartments of the knee joint: medial, lateral and patellofemoral (PF) [26].

The KL grading scale is for classifying the status of OA into one of five grades [29], with 0 representing normal and 4 the most severe disease:

Grade 0: none (definite absence of OA)

Grade 1: doubtful (doubtful narrowing of joint space and possible osteophyte)

Grade 2: minimal (definite osteophytes and possible narrowing of joint space)

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Grade 3: moderate (moderate osteophytes, definite narrowing of joints space, some sclerosis and possible deformity of bone contour)

Grade 4: severe (Large osteophytes, marked narrowing of joint space, severe sclerosis and definite deformity of bone contour).

E. Quantification of Signals

The waveform obtained by the Sound AI contains the field of frequency/time with amplitude. The graphs below displays the level of osteoarthritis on basis of cartilage or meniscus degeneration. Figure 4 demonstrates a Healthy Case with no OA with Average amplitude-27.55 units/recording. Figure 5 shows the moderate or mild OA with Average amplitude - 47.53units/recording, and Figure 6 denotes the extreme OA case with great degeneration of cartilage with Average amplitude - 64.65 units/recording.

The frequency of waves is number of waves/second oscillating over the center line.[22].

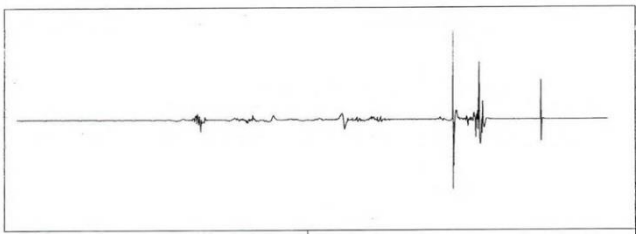

Figure 4:Phonoarthrographic waveform of a control knee

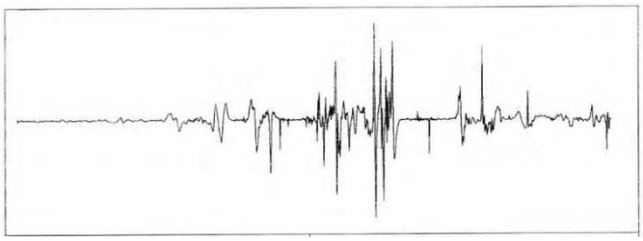

Figure 5:Phonoarthrographic waveform of a moderate case

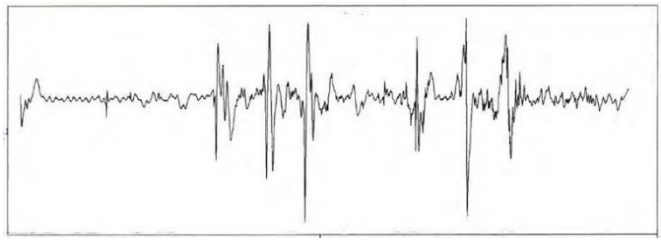

Figure 6:Phonoarthrographic waveform of a severe case

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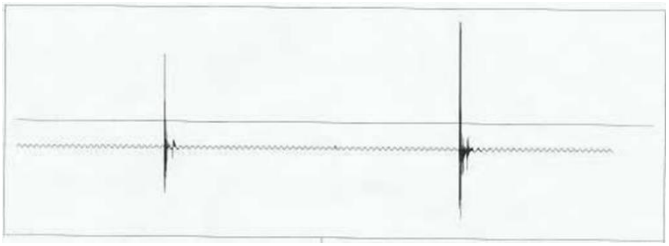

Figure 7: Phonoarthrographic waveform of a case of torn meniscus showing the sharp sound wave appearing twice during flexion and extension.

The Amplitude is directly proportional to level of degeneration as it reveals the amount of cartilage degeneration. In case of using amplitude its advised to consider median/mean value taking as mean amplitude .In certain cases the meniscus tear is denoted with sharp repetition of amplitude that was obtained during flexion on expansion. It is predefined to record sound produced by affected meniscus only leaving behind the sound created during normal locomotion

F. Artificial Intelligence in Data Acquisition and Analysis

Artificial intelligence (AI) is helps in data Acquisition and analysis, which is used to perform cognitive functions such as problem-solving, decision-making, etc. This is used to review the data acquired from different levels and the comprehensive clinical relevance is compared using AI. This data is compared before, during, and after knee arthroplasty. Various data sets are stored from different patents and knee pain , amplitude is measured, this data sets are classified for different categories.

In previous mentioned methodology Microphones, Sensors detected the waveform of sound produced from various joints in body. Later, it required comparing and matching with Kellgren-Lawrence Scale using algorithms in PC or computer. AI is used in various medical applications thus relied upon for Accuracy and reducing Error. Similarly it can be employed in fetching sound input and convert it to digital waveform and Pre-fed diverse dataset from both healthy and degenerated joints is used to analyse the Amplitude parameters of the waveform obtained to derive the average amplitude compare it to K-L scale and displays in the monitor display.

4. DISCUSSION

A. Phonoarthrography versus standard knee radiology

Phonoarthrography a distinct diagnostic methodology should be tried as an alternative of existing methods like Radiology for the joints(here in case considering knee).The Phonoarthrograph obtained later on observation is classified radiologically using the Kellgren-Lawrence(K-L) grading systems according to the severity or level oof degeneration of the knee joints. The patient's knees are phonoarthrographied and classified using the

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radiological Kellgren-Lawrence classification grades (K-L) [22][29] .According to the level of degraded joint its classified into four grade levels.The K-L scale is compared with the obtained values of mean amplitude/frequency. A positive correlation was found between the phonoarthrograph mean values and the K-L graded system containing (P=0.0001).Those mean value exhibited steady increase in value varying as

Grade 1 with mean value 35.04

Grade 2 with mean value 39.55

Grade 3 with mean value 44.27

Grade 4 with mean value 50.53 [26].

Temporomandibular joints shows a clinic-radiologicalarthropathic index (CRAI) that exhibits the duration of pain and sound, level of tissue gentleness and CT od CMC(craniomandibular complex).This CRAI index ranged from0 to 13 from no to extreme OA condition.. This method results where henceforth compared with an artificial neural network (ANN) program to concede the vibration occurring in joints .They were found with accuracy percentage of 98.2% the ANN matched the result produced by the previous diagnosis method used like CT,JVA to analyze TMJ degeneration [30].

B. Comparing musculoskeletal ultrasonography and MRI

The ultrasonography of musculoskeletal was the method employed then to find any abnormalities in the interior or exterior articulating joint surfaces[31]. Understanding of the about the cartilage thickness but not about its surface .On the other hand phonoarthrography provided information about both the smoothness of the cartilage along withcartilage roughness.

The cartilage thickness which was estimated by MSUS are in instances of OA the knees and phonoarthrography was carried out to the same patients [02].It gives vital data about thedenseness of cartilage of both OA patients and control groups and it demonstrates the statical distinction thickness between the both groups (p=0.0001). the thickness of cartilage and radiological grading are inversely correlated.

Phonoarthrography exhibited inverse relationship with the cartilage thickness as it depicts the level of degeneration with decreasing thickness and incrementing mean amplitude. With instance cartilage thickness, average amplitude as r =-0.77, p=0.01 respectively.Next on comparing Magnetic resonance imaging(MRI) it was used to find the disc degeneration and disc, bone changes in condyles and was found that high chances of change in bone was found in degenerated cartilage or menisci disc.They proved advantages of Phonoarthrography for diagnosing the joint structures.It displayed a percentage of 30% and 59% for painful joint and control on obtained images of MRI scan[21].

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C. Comparing Phonoarthrography and Biomarkers of cartilage

As discussed earlier the mean value of amplitude has direct relationship with the cartilage thickness and also determined other factors like matrix metalloproteinase(MMPe disc menisci of the articulating joints by the enzymes released by synovial nodes and chondrocytes. MMP-3 plays vital role in degeneration by degrading the types of Collagen(II,IX,XI) [32].But these biomarkers provide information of joint deterioration of Osteoarthritis rather in case of Phonoarthrography, it provides current status of the cartilage joint.

D. Artificial Intelligence versus Conventional Methodology

Employment of Artificial Intelligence found to produce result with 95% even as methodology under development stage[29]. It has drastically reduced the time involved and feasibility of the diagnosis proving as best innovation in field of healthcare. Conventional methods involve using microphone and oscilloscope with limited memory whereas AI can work efficiently over huge datasets providing better noise

5. CONCLUSION

Phonoarthrography is a method of primary non-intrusive diagnosis which can be carried out easily due to its less complex procedure steps. It also provides access to early diagnosis of cartilage degeneration a common case found in Osteoarthritis that lacks in other conventional and predominantly used diagnostic examination like radiology and imaging for which it can be preferred in Rheumatology clinics. It is provided by the data (as sound)calibrated from two gliding articular joint surfaces that works in harmony responsible for locomotion and movement of joints.

Only the cases of finger joint (temporomandibular joint) and knee was analyzed for phonoarthrography . Whereas, we have many other important joint surfaces contributing to movements of hip, shoulder and elbow etc However, implying phonoarthrography for cases of osteoarthritis is much ahead than in diagnosing Rheumatoid Arthritis as the causes of degeneration varies top greater extent.

Clinical analysis to diagnose and prognose Osteoarthritis is under research. Plain radiograph is widely practiced mean for OA patients to detect the damage and illness of degenerated joint. Unfortunately, this methodology causes some cartilage damage when exposed to rays and consumes more time where on the other hand AI performs it accurately in less time. Furthermore, it is great that the detection of pathology is much earlier even before it can be vied in radiography scans.

However, osteoarthritis is a disease that accelerates cartilage degeneration and the research for the accurate diagnostic methods shouldn’t be halted. To summarize, phonoarthrography is a novel non-intrusive technique for early detection of cartilage degeneration as it proves that cartilage degradation is fundamental occurring in osteoarthritis, although aging of the

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cartilages is also an existing reality. Phonoarthrography can go hand in hand with radiological grading and it is totally sensitive to the early cases that can be observed with normal radiology It acts sensitive to crepitus cases and can be prevalent diagnostic method to non-crepitus cases. Phonoarthrography is also recommended at following up cases of degenerative joint disease.Inclusion of Artificial Intelligence by training Artificial Neural Networks(ANN) can be employed for better analysis and error-free result.

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