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Diagnosis of Knee Joint Osteoarthritis using Synovial Fluid Density Measurement based Bioelectrical Impedance

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Abstract:

According to the World Health Organization (WHO), arthritis is the biggest cause of disability worldwide. It is also one of the most common inflammatory conditions affecting the musculoskeletal system. Synovial fluid is often present in the joint area and serves as a lubricant, which is an essential function. The fluctuation in density of synovial fluid may be used to detect arthritis. This might be done to assess the severity of the disease. This work provides a non-invasive approach for measuring changes in synovial fluid density based on the electrical bio-impedance idea. The purpose of this study approach is to measure change. The current research studied the parameters estimated by bioelectric impedance spectroscopy (BIS) in persons with healthy knees and knees with osteoarthritis (OA). A comparison was done between the two groups of people. Because tissue may be represented as both resistance and capacitive reactance, bio-impedance values are calculated using the voltage drop in relation to the joint tissue area. When the frequency and voltage are held constant, the resistance and reactance values change from a healthy individual to a patient with arthritis. This happens even when everything else stays the same.

Keywords: Synovial fluid density, Arthritis, Knee; Sensors; Biomedical monitoring; Bioimpedance; Osteoarthritis; Older adults; Knee Osteoarthritis; Pain; Older-Adults

I. INTRODUCTION:

Roughly 250 million people throughout the world are afflicted with osteoarthritis (OA), which is a significant contributor to the disability that people experience [1]. A main source of disability, it is one of the most prevalent inflammatory diseases that affects the osteoarticular system and occurs in a significant number of people. When compared to other human joints, the knee joint is one of the most susceptible to degeneration. This is for a number of reasons, including its location, function, and vulnerability to damage. both [2] and [3]. The joint disease known as osteoarthritis, or OA, is a degenerative condition that affects all of the articular

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tissues. Damage to articular cartilage is the most obvious symptom of osteoarthritis (OA). both [4] and [5]. The synovial fluid density examination is a clinical diagnostic test that is used to evaluate the amount of synovial fluid that is present in the cavities of the synovial joints. An abnormal density of synovial fluid may be an indication of a number of different joint problems, such as arthritis, infection, and inflammation. Currently, research is being conducted to determine how the density of synovial fluid may be used to diagnose arthritis. The analysis of synovial fluid, which includes the measurement of density, may be beneficial to both the diagnosis and management of pain associated with arthritis. The following are some of the ways that synovial fluid density investigations can be able to help identify arthritis. When diagnosing arthritis, X-rays, blood tests, and an analysis of synovial fluid samples are often used as diagnostic tools. On the other hand, X-rays may not be able to detect arthritis in its early stages, and blood tests are not designed to diagnose arthritis yet. An analysis of synovial fluid may offer a more definitive diagnosis, despite the fact that it is associated with invasive procedures. When it comes to evaluating the density of synovial fluids, electrochemical bioimpedance is a method that does not involve any invasive procedures. The resistance of a biological tissue is referred to as its bioimpedance, and it is measured when an electrical current is sent through the tissue that is being studied. When comparing healthy joints to joints that have been affected by arthritis, it is reasonable to anticipate that the electrical properties of synovial fluid will be different within each group. In order to determine whether or not bioimpedance can be used to diagnose arthritis, researchers are investigating the possibility. It has been established via research that bioimpedance testing has the potential to differentiate between joints that are healthy and those that are affected by osteoarthritis or rheumatoid arthritis. On the other hand, further study is required to confirm the accuracy and dependability of this technology before it can be used to detect the different types of arthritis. At the present time, the measurement of the density of synovial fluid is not a generally used approach for diagnosing arthritis. In order to determine whether or not it is effective, more research is necessary before it can be used in clinical settings. It is possible that studies into the density of synovial fluid, in conjunction with further biochemical and microscopic examinations, might be of use in distinguishing between the various types of arthritis. Rheumatoid arthritis (RA), for instance, is characterized by the production of synovial fluid that has a decreased density. This is because of the higher protein content and inflammation that occurs in RA. On the other hand, those who have osteoarthritis (OA) may have a higher density because of the degenerative changes that occur and the creation of osteophytes. Synovial fluid density may be utilized as a measurement tool to determine the degree of inflammation that is present in the joint. It is common for synovial fluid to have a lower density when inflammatory arthritic conditions, such as rheumatoid arthritis (RA), are present. This is because these disorders are characterized by a higher protein content as well as an increased infiltration of immune cells. In the case of arthritis, it is possible to utilize sequential measurements of synovial fluid density

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to evaluate the development of the illness as well as the patient's response to treatment. It is possible that there is a connection between the changes that occur in the density of synovial fluid over time and the changes that occur in the efficacy of therapeutic regimens or the activity of the illness. By providing information on the underlying pathophysiology, disease activity, and treatment response, synovial fluid density evaluation is an essential technique for diagnosing and treating arthritis. This is because it offers information on the response to therapy. Generally speaking, this is due to the fact that it offers information on the activity of the illness. Nevertheless, in order to offer a comprehensive diagnosis of arthritis patients, it is necessary to assess the data on synovial fluid density in conjunction with clinical observations, imaging studies, and other laboratory tests.

LITERATURE SURVEY:

The synovial fluid that is present in the body is responsible for lubricating the joints. It is possible that arthritis is present if there are changes in its properties, notably its density. When referring to the way in which an individual's physiology responds to an alternating current, the term "bio-impedance" is used. The bio-impedance data that has been acquired is used for the purpose of diagnosing severe abnormalities in a variety of systems that are present inside the human body. For the purpose of detecting impedance signals, each method involves the placement of electrodes on the surface of the body in a different configuration. In the field of biomedicine, electrical impedance spectroscopy (EIS) is utilized for a wide range of purposes, such as the characterization of tissues [6], the identification of diseases [7]-[9], the analysis of body composition [10], the monitoring of cardiac function [11]-[12], the monitoring of muscle condition during athletic activity [13], dentistry [14], and a wide variety of other diagnostic fields. A loss of equilibrium between the breakdown and repair of joint tissue is the root cause of the structural abnormalities that are associated with osteoarthritis [15]. Loss of articular cartilage and degradation of joint cartilage are two kinds of joint tissue changes that are characteristic of osteoarthritis [16]. Subchondral bone cysts, increased thickness and alterations in the architecture of subchondral trabecular bone, new bone formation at joint boundaries (osteophytes), and osteophytes are some of the symptoms that patients with osteoarthritis mention [17]. [18] [18] Synovial hyperplasia, fibrosis, capsule thickness, and, in certain instances, lymphocyte infiltration are the three characteristics that are used in this particular study. tear formation or erosion of the meniscus tissue [19]. The weakening of the muscles [20]. Bone marrow abnormalities are the sixth point (21). When it comes to the clinical evaluation of primary joint issues as well as systemic illnesses that are characterized by joint effusion, arthrocentesis and joint fluid analysis are quite important. If we compare arthrocentesis, which is used to extract synovial fluid for testing, to pleurocentesis or abdominocentesis, we find that arthrocentesis is neither more complex nor more hazardous than the other two procedures.

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According to the findings of a study, the frequency of depression among older people who suffered from osteoarthritis was three times higher than that of the general population. Furthermore, there is a correlation between feelings of mourning and increasing levels of discomfort as well as a reduction in activity. This indicates how the disease impacts the individual's quality of life, both in terms of their physical health and their emotional health. Because of its resemblance to the white part of an egg, the organ that is known as synovia was given its official name. A buildup of fluid in certain joint areas is an example of synovial fluid, which may be described as a fluid accumulation in the joint. This ultrafiltrate of blood plasma is made up of a very large number of essential components. Hyaluronan, lubricin, proteinase, collagenase, and prostaglandins are some examples of these constituents. The joint space in articular cartilage is lubricated by this fluid, which is physiological in nature and serves as a lubricant. According to the findings of Prekasan et al. [22], synovial fluid is composed of hyaluronic acid and includes 2% protein, which is comparable to the composition of blood plasma. It contributes to the knee and elbow joints by providing them with natural lubrication. In accordance with the findings of Seidman and Limaiem [23], during a gross examination, doctors examine the viscosity, clarity, volume, and color of synovial fluid. Consequently, this makes it possible to more easily identify the symptoms that are connected with joint infections. Morea et al. [24] explored the rheological characteristics of synovial fluid as well as the different therapeutic options available for osteoarthritis. Mairan et al. [25] studied the relationship between synovial fluid and joint lifespan. Wang and colleagues [26] presented a method for measuring viscosity that could be done online. A piezoelectric torsional transducer and electrochemical impedance are the foundations upon which this technique is built. In the research that they conducted [S5 17], Iqbal and his colleagues studied whether or not it would be possible to identify synovial fluid from human knee joints by autonomous means. They conducted research on magnetic resonance imaging and developed automated detections based on deep learning by using transfer learning techniques. The firm of J. Pinheiro and Associates [27]. Both patients who suffer from hip osteoarthritis and healthy individuals should have their lower limbs evaluated for their bioelectrical impedance characteristics. This is an extremely important step. The authors in question are S. Critcher and colleagues [28]. In order to determine whether or not knee tissue bioimpedance is associated with people's knee pain experiences, the purpose of this study was to collect self-reports of knee pain and localized knee tissue bioimpedance from older adults who either had or did not have knee osteoarthritis over the course of seven days while they were living in free-living conditions.

SYSTEM DESIGN:

When it came to the development of the knee impedance measurement system, the three most important problems that were taken into consideration were portability, high degree of flexibility, and low complexity of the hardware. For testing to be able to take place outside of

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specialized medical facilities, such as sports centers, outdoor training centers, or even in the comfort of one's own home, portability is a crucial component. Furthermore, it is essential that the complexity of the hardware be kept to a minimum in order to facilitate the reproduction of the required hardware for system testing by other research organizations, particularly those that are in the medical field and interested in the applications of bioimpedance measurements. For the purpose of experimenting with a wide range of data collection and elaboration tactics, it is essential to keep a high degree of flexibility. A significant amount of adaptability may be easily attained via the use of Digital Signal Processing (DSP) technology for the purpose of generating signals and obtaining detailed data.

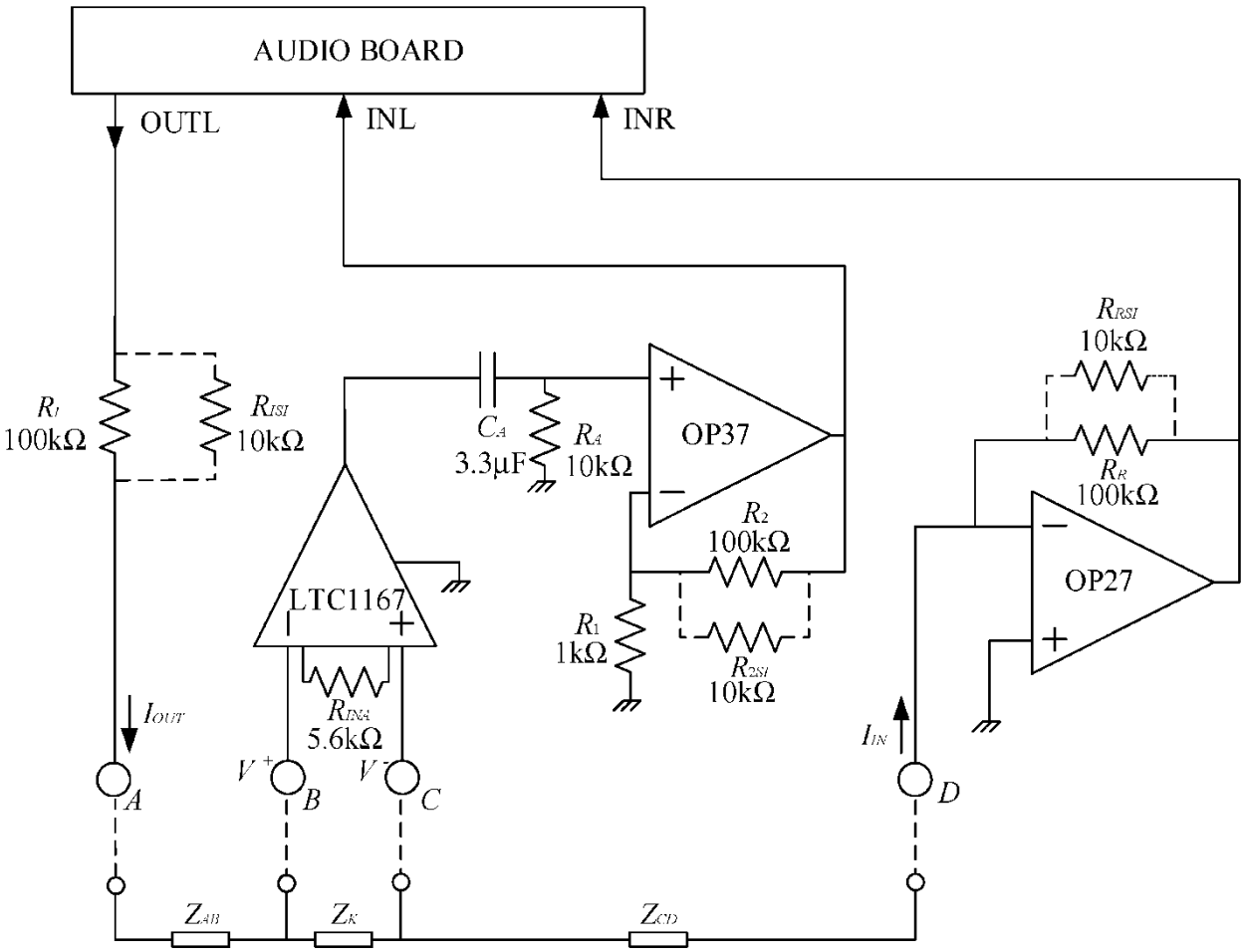

Fig: 1. The suggested system's circuit diagram. As for the parasitic impedances between electrodes A and B, ZAB, and C and D, respectively, we get ZCD and the knee impedance, ZK.

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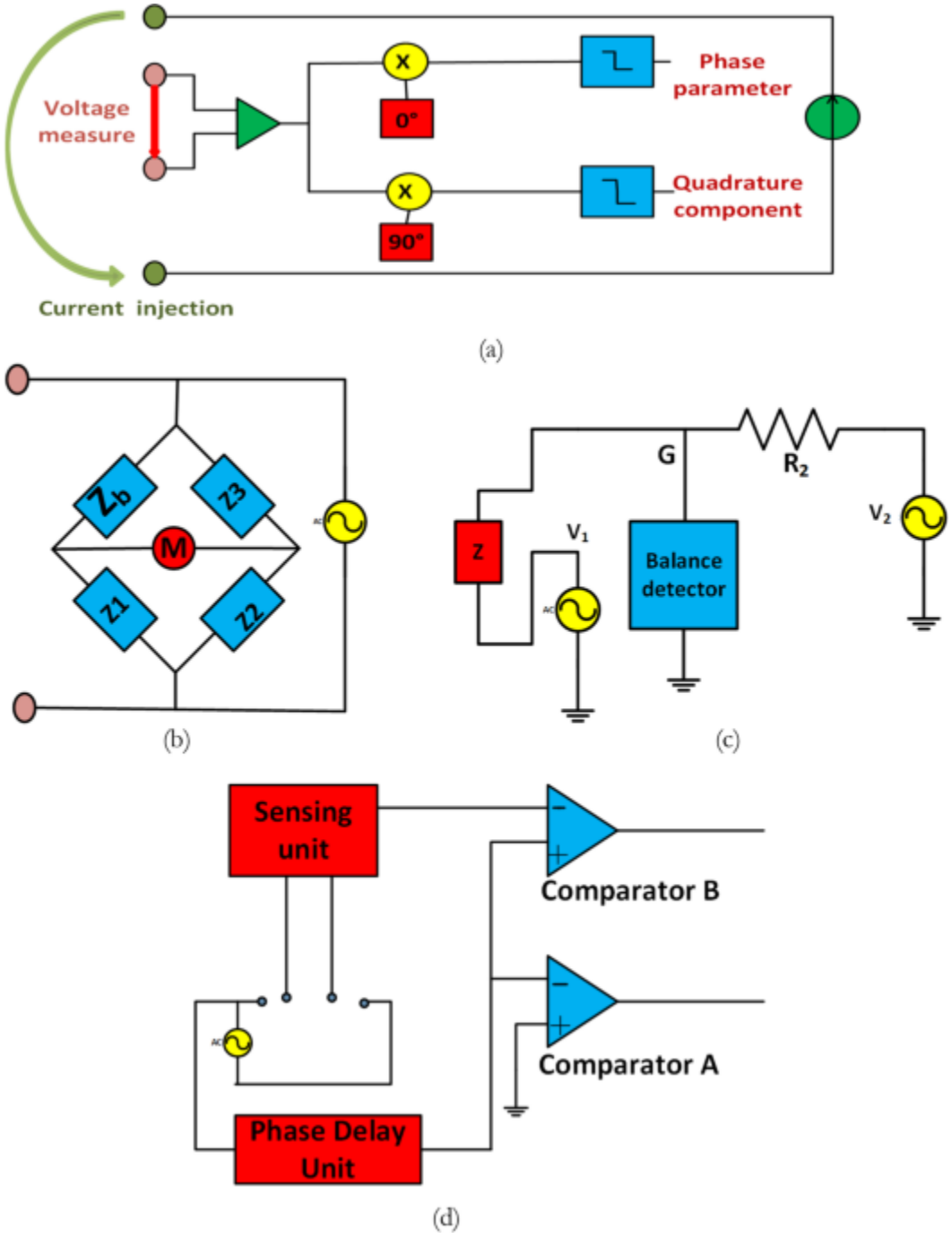

Fig:2 Sensor Device's Circuit Diagram

Using a signal generator that was able to change the frequency from 10 KHz to 500 KHz and the voltage from 0 V to 8 V, the non-invasive device for the diagnosis and treatment of arthritis was constructed. In order to establish noninvasive contact with the joint area, four electrodes were utilized. The purpose of the four electrodes was to simultaneously collect the

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tissue's reaction to electrical signals that were delivered to the tissue area while also sending electrical signals to the tissue (7, 8).

EXPERIMENT:

It is essential to keep in mind that this is an experimental project, despite the fact that Arduino is capable of constructing a bio-impedance device that can assess the density of synovial fluid. It is necessary to have competence in electrical engineering in order to construct a bio-impedance device. Additionally, certain components that are beyond the capability of a typical Arduino board are needed for the device. The detection of voltage and the diagnosis of knee arthritis were both accomplished via the use of appropriate bio-impedance sensors in this research attempt. In addition, the capabilities of an Arduino computer to measure analog voltage were used. Synovial fluid is mostly used to lubricate joints, which is its primary function. In spite of the fact that there is no defined technique for assessing the consistency of synovial fluid, it is possible to learn about the characteristics of synovial fluid by monitoring its thickness. The Kellgren-Lawrence (KL) grading technique was created in order to evaluate and measure the degree of severity associated with osteoarthritis [29]. Grades ranged from 0 (normal) to 4 (dominant osteophyte, severe joint space restriction, and/or bone sclerosis). Normal grades were assigned to patients with healthy joints. In terms of ratings, the lowest possible was normal. 14 patients with grade 0 degenerative changes and 11 patients with grade 1 degenerative modifications were included in the control group. The K-L scale was used to evaluate the condition. The study group, on the other hand, had 39 people recognized as having grade 3 degenerative abnormalities and 18 individuals were identified as having grade 4 degenerative anomalies on the K-L scale [29]. Examples of X-rays are shown in Figure 4.

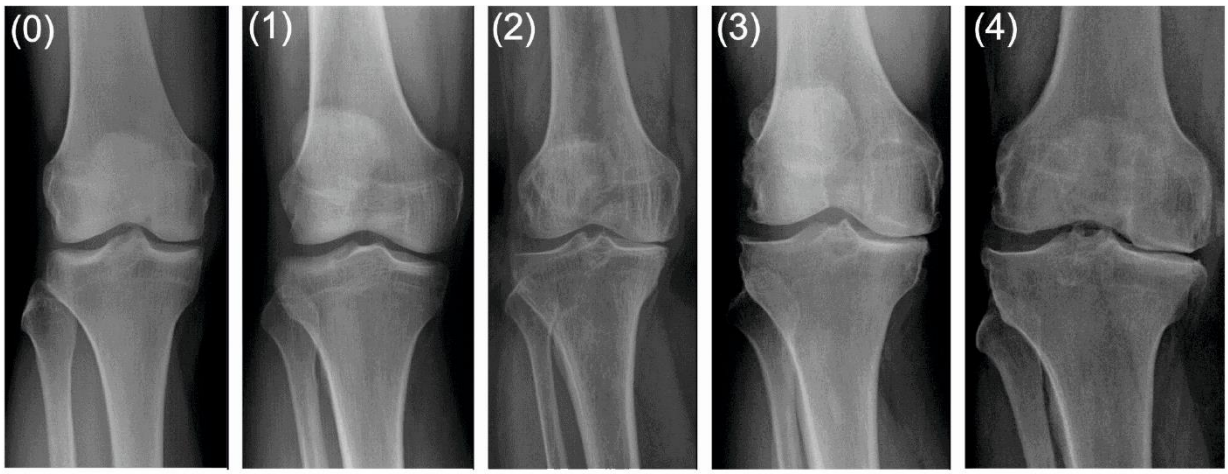

Fig 3 . The Kellgren-Lawrence scale ranks the severity of degenerative alterations from 0 (none), 1 (some uncertainty), 2 (some reduction), 3 (moderate), and 4 (severe).

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While the mean age of the study group was 69 ± 7.5 years (ranging from 49 to 84 years), the mean age of the control group was 50 ± 4.3 years (ranging from 42 to 60 years). On the basis of body weight ($p < 0.012$), height ($p < 0.0001$), and body mass index ($p < 0.001$), there was a noteworthy correlation between the control group and the study group.

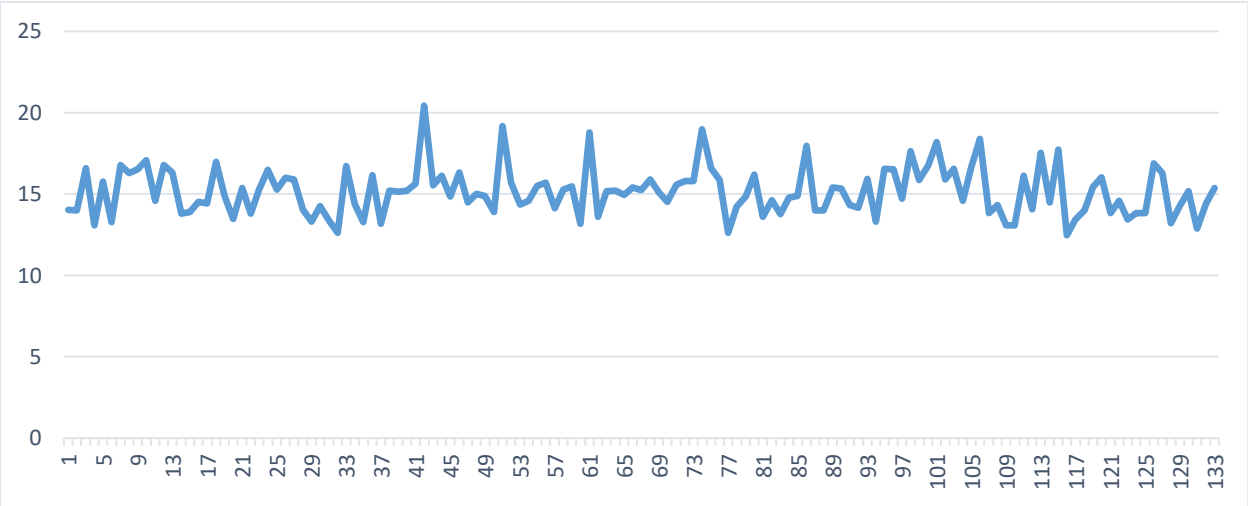

Fig 4: Assessment of Synovial Fluid Density in Patients with Severe Conditions

CONCLUSION:

The present study looks at the features of bioelectric impedance spectroscopy (BIS) in healthy knees and knees with osteoarthritis. Increased or decreased density of synovial fluid, a lubricating fluid found in joints, may indicate the presence of arthritis.

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