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A STUDY OF WAVELETS AS DIAGNOSTIC AND THERAPEUTIC TOOL FOR KNEEJOINT PROBLEMS

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ABSTRACT

The primary objective of this chapter is to provide a high-level overview of the biomechanical characteristics of synovial joints. This has been done as part of the investigation work that has been carried out under the study subject connected to the use of wavelets. In this day and age, it is common information that one in two people struggle with joint pain at some point in their lives. There are many various kinds of joints that canbe discovered inhuman bodies, butthesy novial joint saretheonesthat are of primary importance since they are the joints that maybe described as joints for quality of life. The knee joint is unique among synovial joints in that it serves two purposes at the same time. These purposes include load carrying capability (both the body's weight and any extra weight that may be necessary) and mobility. The knee joint in the human body is one of the biggest and most complicated of all the joints. When there is no sickness and no deficit, then everything operates properly, and the intricate network that makes up the human knee joint works in harmony with the other parts of the body. If, on the other hand, there is a sickness or injury that disrupts the normal functioning of any network of bodily components, then medical therapy, with or without surgery, is the only viable choice for repair.

Keywords: Wavelets, Diagnostic, Therapeutic Tool, Kneejoint Problems, biomechanical characteristics

Introduction

In general, synovial joints are regarded to be the most active joints in the human body. One specific synovial joint, the knee joint, is only ever replaced in the most extreme of extreme circumstances when it is damaged by illness or accident. Arthritis is the medical term for a debilitating condition that causes joint pain. There are many distinct forms of arthritis as well as disorders that are associated with it. Arthritis is a degenerative joint disease that may affect anyone of any age or gender and severely impairs their capacity to do even the most basic of

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day-to-day tasks. The knee joint and the hip joint are the joints that are responsible for bearing our complete body weight and allowing us to carry or pull heavy things. Cartilage is the term of the cushioning surface that may be found at the end of joint bones in these joints. This cartilage begins to deteriorate over time, which ultimately results in the formation of cysts and bony spurs at the ends of the joint bones. Osteoarthritis is the name given to this particular kind of degenerative arthritis (OA). Rheumatoid arthritis is a kind of arthritis thatisvery common(RA). RAisanautoimmunecondition, which means
that our immune system assaults the soft lining surrounding our joints, mistaking itfor a virus or bacterium. This leads to bone deformities over time.

Synovial joints are built by nature in such a manner that there is little wear and maximal friction, allowing them to fulfill their role without failure for the longest possible period of time. As a result, synovial fluid plays an essential role in the field of study. Primarily, there are two primary goals that should be pursued in synovial joint research: First things first, let's have a look at the fundamentals of the natural lubricating process. Second, the production and use of artificial joints that may be beneficial in the process of replacing joints. Mathematical models have been used to provide predictions about answers to common questions whose answers are difficult to determine by experimentation.

In the case of the knee joint, a great number of scientists and researchers arecurrently working on the bio-mechanism of the joint lubrication in such a way that intricate numerical computations can be carried out with the assistance of sophisticated models that are able to produce the desired results. Wavelets andmodels based on wavelets serve as the best part due to the ordered organization and localization feature. There have been many articles published that emphasize the application of wavelet methodology in biomedical engineering. Wavelets and models based on wavelets serve as the best part.

BIOPHYSICAL, CHEMICAL AND MECHANICAL ASPECTS OF SYNOVIAL JOINTS

The structure of a synovial joint is made up of two connecting bones that are separated by voids that are filled with synovial fluid and cartilage. This synovial fluid that was discovered is either colorless or sometimes has a yellowish tint, and its volume ranges from 0.2 to 0.5 milliliters. Synovial fluid is chemically composed of a portion of protein plasma, which is one of the factors that contributes to its rheological feature.

A large number of scientists and researchers have investigated the many functions and material constants that are used in rheological fluid models, which are proposed for synovial fluid lubrication. The fluid with a higher grade that acts as a lubricant in the synovial joint was modeled by Nigam et al. (1983). They came up with an analytical formula to describe the load bearing capability as well as the pressure distribution.

Ingeneral, thepressure That Is Createdinthe Jointcavity By youthful synovial fluid is greater when compared to the pressure that is produced in the joint cavity by the synovial fluid of an elderly person or a person with osteoarthritis. The most minimal pressure distribution was seen in the center and at exists. It was found to be most prevalent in the areas that were considered intermediate. When compared to normal, old, and OA synovial fluid, the time it takes for two surfaces of bones to approach one another duringthe formation of youthful synovial fluid is much shorter.

It is thought that when two bones approach each other when there is no or very little synovial fluid present, the spherical surface of the bones at the exit will begin to approach a planesurface. Thisisbecause synovialfluidacts as acushion between the bones. When the body is in an upright posture, such as standing or leaping, the synovial joint bones make touch with one another for a longer period of time.Because of this, the cartilage structure eventually becomes severely worn down.

Now that we have that out of the way, let's talk about muscle activity, which is a biomechanical component of synovial joints. The way humans walk may be thought of as a chain of events with causes and consequences. On the topic of human walk, a number of studies and hypotheses have been published, and tests have been carried out. There are four primary components that make up the knee, and they are the bones, the ligaments, the cartilage, and the tendons. The knee is made up of three bones: the femur, which is a bone in the thigh, the patella, which is a bone in the kneecap, and the tibia, which is a bone in the shinbone. The assistance of ligaments is required in order to accomplish the joining of bones to one another.

There are four different kinds of ligaments that work together to keep the bones in place and give the knee its stable posture. There are a total of four ligaments present in the knee joint, however the two most important ones are the cruciate ligaments. The Anterior Cruciate Ligament (ACL) and the Posterior Cruciate Ligament are the names given to these ligaments (PCL).

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These two ligaments join together to create an X, and in this configuration, the anterior cruciate arrives first, followed by the posterior cruciate. In the first place, the biomechanical function of the human knee joint may be broken down into the following categories:

The anterior cruciate ligament (ACL) stops the tibia from sliding forward on the femur and the femur from sliding backward on the tibia at the same time. • The posterior cruciate ligament (PCL) is located deep inside the knee joint. Additionally,it descends in a diagonal direction and is distinct from the fluid-filled synovial cavity. It prevents the tibia from moving posterior to the femur and stops the femur from sliding rearward on the anterior margin of the tibia.

The side sliding position of the femur is prevented by the femur's other two ligaments, the medial and lateral collateral ligaments.

Cartilage in the knee is responsible for the smooth and painless functioning of the joint. The articular cartilage and the meniscus cartilage are the two forms of cartilage that are located inside the knee joint. The smooth covering that lies atop joints and protects the ends of bones is called articular cartilage.

Thekneeismadeupofseveralsacsthat arefilledwithsynovialfluidandpromoteits smooth functioning. Allow the force L = L(t) to begin exerting its influence on the individual either when they are still or when they begin to move. When L is morethan zero, the femoral condyles and the tibial plateau are compressed closer together. When L is less than zero, the squeeze film effect is activated.

This lends credence to the notion that fluid in the knee joint is either expelled into or pulled out of the cartilage. Because cartilage does not get its nutrients from the blood stream, thesynovial fluid must do so instead. It has been observed that when aperson remains immobile in a standing position for an extended period of time, synovialfluid is forced out of the space between the tibia plateau and the femoral condyles, resulting in the connection of the bone surfaces that are covered in cartilage in a straight line.

MATHEMATICALMODELLINGOFSYNOVIALFLUIDFLOW

Mathematical modeling is a method that has proved beneficial in explaining a variety of phenomena relating to physical, biological, and engineering, to mention just a few ofthepossibleapplication areas. Modelingoften results in amathematical scenarioin which the system is represented mathematically by an equation, such as an ordinaryor partial differential equation. In the mathematical analysis, the knee joint is represented as a cylinder that has a plane for its configuration. It is the most practical approach to use when modeling and analyzing synovial joints of this kind. The bones that make these joints are subject to all of the properties of a simple solid, including the rigidity attribute.

Articular cartilage, which consists of a porous layer and an elastic type substance, serves to separate the many joints that make up a human knee. Synovial fluid, which is a Newtonian lubricant, is what fills the space that is otherwise empty in between these joints. Calculating the pressure that the human bodyexerts on the synovial fluid bymakinguseofits structure, angles,and velocitiesofsurfaces maybedonewith the assistance of Reynold's equation, which is presented as follows:

ThefollowingisamodifiedversionoftheReynoldsequation,whichrepresentsthe conventionallubricationtheory:

$$\frac{\partial}{\partial x}\left\{\frac{\rho h^3}{12\mu}\frac{\partial p}{\partial x}\right\}+\frac{\partial}{\partial y}\left\{\frac{\rho h^3}{12\mu}\frac{\partial p}{\partial y}\right\}=\frac{\partial}{\partial x}\left\{\frac{\rho h(u_a+u_b)}{2}\right\}+\frac{\partial}{\partial y}\left\{\frac{\rho h(v_a+v_b)}{2}\right\}+\rho(w_a-w_b)-\rho u_a\frac{\partial h}{\partial x}-\rho v_a\frac{\partial h}{\partial y}+h\frac{\partial p}{\partial t}$$

Intheaboveequationfollowingparametersandnotationsareused:

- Pressure of synovialfluidfilm:p
- CoordinateslikebearinglengthandwidthareinCartesiancoordinates.
- Synovialfluidfilmthickness:h
- Synovial fluidviscosity:µ
- Densityofsynovialfluid:ρ
- Velocitiesofboundingbodyindirectionsx,y,andzareu,v,andwrespectively.
- Subscripts a, and b in equations depicts top and bottom bounding bodies. Boundaryconditionswhichwereconsideredwhilemodifying Reynold‘sequation was-at inlet For the solution of $p=0$, at outlet $p=\frac{\partial p}{\partial x}=0.$

Reynold's equation following assumptions were considered like, smooth surface, Newtonian fluid, Iso-viscousfluid, steady state condition, Incompressible fluid, Inertia effect neglected, and Isothermal condition. Because of these assumptions, it was possible to predict the pressure that was applied to the lubricating fluid, which led to the development of a modified version of Reynolds' equation.

With the assistance of the average flow model, the finite element approach, and the finite difference method, this equation has been solved by using a variety of assumptions and approximations.

In the beginning, a modified version of Reynolds' equation was solved in order to acquiretheresultofthepressurethatisexertedandtheimpactthatithasontherough surface when bones have covering of partial lubrication. Following that, a great deal of alterations were implemented, and a great deal of approximations were computed. By employing wavelets, Bujurke et al., 2007 were the first people to present one of the ways for solving modified Reynolds' equation. This method makes use of wavelets.

CLASSICAL LUBRICATION THEORY VIA MODERN WAVELET THEORY(ABRIEFREVIEW)

The fibrous joint capsule that surrounds and connects the synovial joint is another name for the condition known as diarthrosis. The cavity that it has is stuffed with synovial fluid, which is characterized by a linear viscosity. In light of this attribute, Hou et al. conducted an investigation on the lubrication of the film that was obtained by squeezing cartilage (Mansour et al., 2013).

This particular kind of joints, which was presented by Mansour et al., is seen to as a porous, permeabilous, deformable, and elastic material, and its cavities are thought to be filled with a single layer of homogenous fluid. In an essay that was detailed by Torzilli and Mow, the physical features of articular cartilage were explored.

This was done because of the connection that it makes during functioning to the movement of fluid through the tissues. They also explored the non-Newtonian property of synovial fluid and showed cartilage for interstitial fluid using the traditional hydrodynamic lubrication theory (Torzilli and Mow, 1976). Both of these studies were published in 1976.

It is well knowledge in the field of engineering practice that soil that is subjected to a load does not instantly rebound but rather settles slowly at varying rates. When clay and sand are submerged in water, they take on a quality that is analogous to that of water itself.

Consolidation of the soil is the term used to describe this sort ofbehavior,whichoccurs whenthesoilissubjectedtovaryingloads. It wouldseemthat this mechanism is the same as the one that removes water from an elastic porous media.

A model of soil consolidation that was presented by Biot involves a very simplelinear kind of biphasic mixture that is made up of an elastic porous deformity matrix. Of order to represent the movement of synovial fluid across the articular surface in synovial joints, this model has been employed (Mansour, 2013; Torzilli and Mow, 1976; Forster and Fisher, 1996).

A further researcher bythe name of Collins presented a prototype for cartilage, which assisted in the formation of poroelastic matrix, using this hypothesis of Biot as the core theory (Collins, 1982). Additionally, the unsteady flow equation for an elastic porous medium that is provided by Darcy's law is satisfied by this prototype. Despite this, there were a few inconsistencies that made it possible for some modifications to be reported in (Ateshian et al, 1998; Jin et al., 1992; Hlavacek, 2000).

Thesubsequentstudythatwascarriedoutbyalargenumberofresearchersmadeuse of a model that is composed of an elastic single phase and a single phase model for synovial fluid. It was necessary to build a number of models, each of which was predicated on an apparently unique set of assumptions, in order to establish a link between the numerous characteristics that were being studied and to arrive at correct predictions about the various phases and kinds of knee joint The pressure, deformation, and flow within a two-dimensional poroelastic medium have all been calculated using the aforementioned numerical methods and computer simulations.

A theoretical investigation on the lubrication of slider bearings with reference to synovial joints was carried out by Bujurke with the use of fluid of the second grade. Ananalyticalequationwasdevelopedthattakesintoaccountthefollowingfactorsfor the human knee joint: the frictional force, the load bearing capacity, and the pressure distribution.

The fact that the fluid was non-Newtonian had a substantial impact on these characteristics. Young synovial fluid was shown to have a much higher frictional coefficient, frictional force, and load bearing capacity when compared toosteoarthritic and older synovial fluid samples utilized in the research (Bujurke, 1982).

A new discipline known as computational fluid dynamics (CFD) was established a few years ago with the assistance of computational mathematics and computer science. This new subject was given its name. In order to explain how synovial joints work, the property of wavelets known as localization in space and scale was used for governing equations in the form of sparse representation, for the functions and operators that arise in the form of partial differential equations, and for the governing equations themselves.

Using numerical and pictorial data, biomedical engineers have selected appropriate parameters and materials for building and manufacturing prosthetic knee joints. This discovery justifies the study and research connected to the functioning of synovial joints.

The bones of a knee joint that is synovial are separated from one another by a very thin layer of synovial fluid. Traditionally, the solution to Reynolds' equation has been presented in the form of a partial differential equation. This has been used to determine the pressure distribution of a thin viscous fluid layer.

The researchers Bujurke et al., 2007 made an effort to adapt the Reynold equation by takingintoaccounttheroughnessstructureofthearticularcartilage.Theelastic quality of cartilage was modeled using this modified equation, and the roughness of the tissue's structure was investigated using the traditional multigrid approach. There are certain restrictions with the multigrid approach. One of the drawbacks is that it does not generate output for equations that include oscillatory coefficients or incoherence, such as elliptic issues.

This is one of the constraints. A new approach, known as the fast wavelet-multigrid method, was developed in order to solve the modified Reynold equation and to overcome the constraints of the multigrid method. This new method includesd wavelets and was given the name fast wavelet-multigrain method (Bujurke, 2007).The wavelet transform allowed for a solution to be quickly and precisely discovered.

A research was carried out with the assistance of this approach, which proved to be beneficial in determining the lubrication performance as well as the poro-elasticity effects in synovial joints. It was shown that the pressure distribution and load carrying capacity were increased to some degree when pair stress fluid and poro- elastic bearings were employed as lubricant. This improvement was only noticed to a limited extent, however (Bujurke, 2007).

CONCLUSION

In-depth research is being conducted on a wide variety of approaches and models of the biomechanical function of synovial fluid, with a particular focus on wavelet technique. Our primary emphasis was placed on describing the mathematical model and the methodology that was used by a variety of authors, performing an analysis of the various features of these models, and arriving at certain results that would enable bio-medical engineers to select appropriate design factors. Some of the metrics, such load bearing capacity, frictional force, and sliding velocity, are useful in offering an insight into the intricacy of the construction and operation of synovial joints. [Citation needed] The analysis of the modified Reynolds equation asit relates to the performance of the knee joint is the focus of this chapter, which is distinguished by its presentation of the relevance and usefulness of wavelets and wavelet packets in this inquiry. The most important findings from the ongoing study and the consequences those findings will have in the actual world may be obtained for the benefit of the technical community, which is the aim of the work that is now being made.

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