A STUDY OF SOME BIOMEDICAL FINITE ELEMENT MODELS

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ABSTRACT

Finite Element Model (FE Model), based on a numerical technique called Finite Element Method (FEM), plays a vital role for providing solution of complex biomedical problems. With the rapid advances in computer technology, sophisticated FE Model of the human body has been developed in recent years. This includes FE model for biomedical problems and treatments like Percutaneous valve implantation- a successful alternative to open-heart Surgery, Tissue Modelling, and analysis of deformation of various parts of human body. The 3-Dimensional FE models can be effectively used to address the medical problems, internal injuries and diseases related to knee, joints, bones, heart, kidney and various other human body parts. In this paper, a brief summary of some FE Models of biomedical problems related to human anatomy is provided. A study on developing some FE Models for biomedical problems of different nature and areas is highlighted here.

Keyword: - *Biomedical problems, FEM, FE Model, Human anatomy*

1. INTRODUCTION

During recent years there has been a rapid development and an increasing interest in the numerical solution of biomedical problems. Development of a powerful model to understand and predict biomechanical phenomena of the inner human body is an important task as it is not possible to measure the forces and pressure inside the human body. Finite Element Model (FE Model), based on a numerical technique called Finite Element Method (FEM), plays a vital role for providing numerical solution of complex biomedical problems related to human anatomy[1]. Compared to the rapid advances in computer technology, only few sophisticated FE Models of the human body have been developed in recent years, due to its complexity. For medical diagnosis, injury mechanism, visualization, model-based treatment and therapy planning, visualization of surgery simulations, three-dimensional (3D) geometric reconstructions of *individual* specific human anatomy are often indispensable. The human anatomy has irregular shape and varies with the position, age, gender and individual. Modelling the human anatomy is very difficult because of its complex geometry and composition of systems like musculoskeletal system, nervous system and circulating system. The peculiar nature of FEM, i.e. its application to irregular complex geometry and various boundary conditions, makes it an ideal tool for analyzing living tissue such as bone, which has complicated geometric shapes and inhomogeneous material properties [2, 4]. 3D FE Models can be effectively used to address internal injuries and diseases related to knee joints, bones, heart, kidney and various other human body organs [5]. As it is difficult to experiment on human beings for FE Model, dummy models can be created and tested by using FEM. They are very useful in clinical treatment and decisions like Percutaneous valve implantation- a successful alternative to open-heart Surgery[2, 3], Tissue Modelling, and analysis of deformation of various organs of human body(both elastically and plastically deformations of objects like human flesh).[2]. Unlike other methods (e.g., strain gauge) which are limited to points on the surface, the FEM can quantify stresses and displacement throughout the anatomy of a 3D structure. To improve the accuracy of the result, it is important to consider various factors like segmentation of the anatomical structure, mesh resolution and the choice of the finite elements [14]. With the help of various FEM, combinations with other advance numerical techniques, clinical observations and applying suitable software packages, one can develop a FE model to solve the practical biomedical problems [1].

2. FINITE ELEMENT MODELS RELATING TO HUMAN ANATOMY

2.1 FE Model for Heart

The development and study of the human heart model is important for various cardiac issues and procedures like cardiovascular surgical procedures, computer aided diagnosis and treatment of cardiac diseases and attack, understanding the functioning of the heart and cardiac research. The human heart can be modeled as an elastic body [5], where the dynamic process of heart beating and the blood flow pattern inside the heart can be modeled through FEM such as stabilized Galerkin FEM and Navier Stokes equation. FE modelling is a powerful tool during preclinical testing and used to optimise device design for Percutaneous valve implantation [2, 3]. FEM can enhance the safety and success of the procedure in the device design by selecting the most appropriate prosthesis for any individual patient considering their specific anatomy. Furthermore, FE analysis can help to predict the number of devices required to cover the whole range of patient morphologies. Combination of patient specific imaging data and computational modelling can improve the understanding of heart structures and the way devices interact with them. Further research needs to be done regarding developing more realistic heart model from patient-specific imaging, namely: 3D computational modeling of the human heart for a quantitative analysis of cyclical electrical conductance on the heart membrane, the biomechanical properties (stress-strain, elasticity) of the heart ventricular walls, and the 3D modeling and simulation of pulsatile blood flow through human arteries/veins for vascular by-pass surgery pre-planning[4]

2.2 FE Model for Bones:

Bones are rigid organs which have different shapes, complex internal and external structure and serve multiple functions.[5]. Because of the rapid advancements in computer technology and high-performance computer chips that enable more complex and detailed models with smaller elements, there has been an improvement in the quality of the human bone models also. These models can analyze mechanical properties of complex human bone structure and biomechanical simulations. FEM has its applications to study the biomechanical behaviour of bones under static and dynamic loading conditions and various injury mechanisms. The models help to develop interventions such as training strategies or surgical procedures for the prevention of bone fracture or disease. The mechanical properties of bone are inhomogeneous and patient specific, influencing on the total stiffness and stress condition of the bone. Anatomically accurate FE Model of bones with accurate geometry and material properties retrieved from computer tomography (CT) scan data are widely used at present to study the biomechanical behavior of bone structure and implant fixation. In human anatomy, the femur is the longest and largest bone [6, 7]. Available 3D FE Models of femur bone using CT/MRI (Magnetic resonance images) scan data of either dry or frozen human femur bone are useful to study the effect of nailing and Total Hip Replacement (THR) on it.

2.3 FE Model for Knee Joint:

The human knee is the largest joint in the musculoskeletal system, which supports the body weight and facilitates locomotion[6]. The issues related to human knee joint like, knee replacement surgery, technical aspects of the computational modeling of ligaments, optimization of movements (e.g. in sports) in order to minimize the loads on the joints, understanding injury mechanism, design of the equipments, etc., can be effectively addressed by a combination of FEM and computer simulation technique. Some of the FE Models already in use are, a 3D model to investigate the articular contact of femur and tibia, A model with 798 eight-node solid elements for the cartilage and the menisci, 1212 truss elements for the reinforcing of the solid elements for simulation and compression of the knee joint, restructured model of the same to study the biomechanical influence of varus-valgus, analysis of the tibio-femoral joint in axial rotation.[7]

One can develop a FE Model with slight modifications in existing models for human anatomical structure, including femoral condoyle, tibia condoyle, fibular small head, patellar, cartilage, meniscus and primary ligament. It helps to understand the behaviour of the structures of the human knee joint under dynamic loading, the mechanics of the main ligaments, mechanics of knee joint injury and hence is useful in the design of the vehicle protective devices. [2]. FE Model of ligament mechanics can help in developing the strategies, by which one can have an idea of ligament composition and structure and differentiate between whole-joint models and individual ligaments models.

Knee joint is prone to injury. Osteoarthritis, a chronic disease of human knee joint is one of the most common diseases. FE models, used in determining knee joint mechanics and FE simulations can help in optimization of orthopedic devices[8]. The understanding of the combined role of the knee joint structures in stabilizing and restraining the motion of the joint is fundamental for diagnostic procedures. Even though there have been rapid advances in biomedical field, there is hardly any good research done to understand kinematic and kinetic behavior and the complex injury mechanisms of the joint due to various limitations of experimental studies like, high cost, difficult measuring situation and very little scope for experimental reproduction.

2.4.FE Model for Head and Brain:

The brain is one of the most essential organs of the human body and FE modeling of the human head and brain has been advancing over the recent past. Head or brain trauma is a severe critical condition which causes death, if proper medical attention is not given. To recognize and treat life-threatening conditions and diseases like brain trauma, skull fracture, intracranial hemorrhage, etc. and to eliminate or minimize the role of secondary injury, proper understanding of the biomechanics of brain and skull deformation is necessary[10]. From a number of issues like, brain tumour, blast-related traumatic brain injury, injury mechanism to design of protection devices for road and sports accidents and many other modern scenarios require accurate and realistic model.

Presently various FE Models are in use for addressing these problems. Some of them are, a FE Model for the mechanical response to (impact) loading of the human head to compute the local mechanical response of the different structures(e.g. in terms of pressures, stresses and/or strains)[9], a 3D mechanical model for simulating large non-linear deformations induced by tumors to the surrounding encephalic tissues initialized with the help of 3D radiological images, to simulate the behavior of brain tumors controlled by a parameters related to bulk tumor location, size, mass-effect, etc., an accurate and realistic 3D FE Model of whole-brain to solve the forward problem of modelling and computation of magnetic fields produced by human brain during cognitive processing in magnetic field tomography (MFT) based on Magneto encephalography (MEG)[10], subject specific- a five-layer realistic FE head models based on their magnetic resonance (MR) and CT imaging data for FE analysis of brain electromagnetic field, and many other. To understand brain injury mechanisms and predict impact injuries, one has to investigate material modeling, skull-brain interface conditions, pressure release through foramen magnum, the effects of ventricles and the subarachnoid space, the effects of a three layered skull etc. In spite of many 3D FE head models, the main issues with these models are the lack of a suitable and accurate material model for describing the mechanical behavior of brain tissue, the difficulty in modelling of interface conditions between intracranial structures (e.g. skull and brain), the lack of experimental intracranial impact response data.[9]. Proper study on obtaining more experimental data for comparison is the immediate requirement in head-brain injury research.

2.5. FE Model for Skin:

Skin is considered as multi layers structure of different type of tissues having heterogeneous properties. Due to various characteristics of skin such as skin composition, skin complexion, skin structure, mechanical properties, aging etc., it is a real challenge to accurately model human skin. Skin models have wide range of applications in the field of entertainment, cosmetics, plastic surgery, pharmaceutical, and many others [10]. Modeling of skin is necessary to address various problems and issues such as skin burn, skin cancer, skin wound, wrinkles, aging etc. FEM is used for computing the deformation and to address the issues mentioned above. In FE Model, we consider skin as a volumetric substance having multi layers of heterogeneous materials.

[11]The mechanical characteristics of skin are extremely complex and have not been satisfactorily simulated by conventional numerical models. It is important to understand the physiology of burns and the effect of biological and environmental parameters on temperature distribution inside the skin tissue subjected to heat injury for a successful clinical treatment of a burn patient. Thermal injury, which results from exposure of skin elements to an externally applied heat source can be modeled using the FEM.[12]. FEM, thus helps for numerically simulating steady-state temperature distribution inside a multilayer human skin tissue of skin burn[14]. A sensitivity analysis is to be conducted to investigate how changes in the values of skin parameters such as the thermal conductivity and environmental conditions affect the temperature distribution inside the skin. A good research has been done regarding development of FE Models for skin burn injuries of various situations like, injury due to blast, accident, acid throw, and many other. Some of them are, FE Model of burn injuries in blood-perfused skin, a model for a flash fire exposure, a mesh-independent model to predict skin burn injuries, to present transient temperature and damage function distributions variations for the variations of the initial temperature, blood perfusions and skin layer

thicknesses [13]. Developing a predictive anisotropic, hyper elastic and constitutive model of human skin will help in various skin treatments, product design and replacement of animal models in pharmaceutical, engineering and cosmetic industries [15].

3. CONCLUSIONS

The aim of this paper is to highlight some FE Models which address the latest biomedical problems related to human anatomy. The study of FE Models of human body organs like Heart, Bones(and Knee joint), Brain, Skin presented in this paper, may help in developing more realistic, sophisticated, improved models and also developing FE models of other important organs like, kidney, liver, etc. By using FEM, we can now have improved medical treatment, better implants, improved instruments, improved anesthesia techniques and post-surgery pain management. So, it is important to study FE Models which can be powerful means to understand the structural and functional aspects of molecules, cells and tissues of biological systems, in particular, human anatomy[16]. The FE analysis can help in addressing new challenges in biomedical field and help to overcome major limitations in it. The study can be useful and may have greater impact in a broad range of biomedical sciences and further research in human anatomy.

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