Biomechanical Analysis of Pelvic Bone: A Review

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Abstract

Inorthopedic biomechanics structural-mechanics deals with the stress and strain analysis of bone, joint and implant. Finite element analysis (FEA) is the preferred method for this numerical problems and Finite element method (FEM) is a common tool used for numerical simulation. The study contains the chronological order analysis of structure, material properties, load resistance, chance of failure and strength of human pelvic bone using FEM, along with mathematical method as well as experimental method using drop towers and strain gauges. The primary objective of this review paper is to analyze the behavior of pelvic bone subjected to various loading cases include tension, compression, bending and torsion which is normally experienced during daily activities and in uncertain cases like accident in which pelvic fracture, cracking or breaking of pelvis are extremely common injuries.

Keywords- ***Pelvic*** *Bone, Static and Dynamic Analysis, Three-Dimensional Finite Element Analysis, Material Properties, Mechanical Test.*

I. INTRODUCTION

In the musculoskeletal system the pelvis is one of the most vital component. The pelvis, or pelvic bone, derived from the Latin word 'basin', is an anatomical structure found in most vertebrates [29]. The lower extremities are connected to the upper portion of body through pelvis. The mature pelvic bone is osseous integration of three parts, the iliac, the ischial and pubic bone which can merge to form acetabulum the socket of hip joint, through which pelvic bone interact with femoral head. The role of pelvis is to transfer gravitational and external load under controlled strain across the sacroiliac joint and hip joint. The pelvis is the most important part of the human skeleton, which contributes to the stability of human body and the protection of organs inside. The compressive force of the body weight that passes from sacrum to sacroiliac joint can be resolved into two components, one will go down word and laterally to the acetabulum while the other component goes downward medially to the symphysis pubis. The acetabulum and adjoining pelvic bones are one of the most important weight bearing structures in the human body. Forces as high as 5.5 times body weight are transferred from the femur to the acetabulum during activities such as running and stair climbing. The structure of the pelvis is a sandwich material, with the thin layers of cortical bone carrying most of the load. Despite its efficient structure, the pelvis can become damaged due to altered loading. Side impact forces, such as those generated in car accidents, are notorious for generating pelvic fractures. The fracture itself often causes multiple internal trauma leading to a mortality rate on the order of 12 - 37% [2][24]

II. LITERATURE REVIEW

The pelvic bone mainly consist of trabecular bone covered by a thin layer of cortical bone. Due to sandwich structure the overall mechanical behavior of pelvic bone is insensitive to variation of mechanical properties of its trabecular bone. If stress and strain in the trabecular bone itself are the subject of study, accurate value of material properties will be prerequisite. In order to identify the material properties, dual energy quantitive computed tomography(DEQCT) of six right pelvic bone and non-destructive material testing on two fresh pelvic bone with stereological measurement is used to obtain young’s moduli and Poisson’s ratio in three orthogonal direction and Bone densities throughout the pelvic bone [9].The pelvic bone have to withstand the forces which are multiple the weight of body for which the basic load transfer and stresses distribution under physiological loading condition is analyze which results the major part of the load is transferred through the cortical shell (about 50 times higher than the trabecular bone). Although the magnitude of hip joint force varies considerably [21]. The thickness of cortical bone shell and density distribution of the trabecular bone throughout the pelvic bone have to incorporated in the model in realistic way for development and validation [8].W Davis studied that the height is associated with bone mass difference in opposite direction in which pelvis is not measured [15].Biomechanics of hip during walking was analyze using quasi static analysis, in which pressure force exerted on coxofemoral joint using geometric plane technique considering frontal and sagittal plane is evaluated which is reliable while three dimensional analysis integrate all phenomenon and have exact value [26].Parametric finite element studies of human pelvic was performed under the influence of load magnitude and duration on pelvic tolerance during side impact, which predicts that higher loading rates yielded pubic ramus fracture while lower loading rates yielded acetabular fracture [16]. Analysis for 13 side impact test from no fracture to acetabular fracture is done to simulate automotive side impact on the isolated human pelvis, and lateral impact test to explore pelvis stiffness was done using drop tower which result average impact velocity , impact mass and mean peak force and overall pubic compression [13]. Finite element modeling and experimental verification of lower extremity using new experimental method for modeling the shape of the in situ lower residual limb was developed based on spiral X-ray computed tomography (SXCT) imaging, which result shape change under load [23]. Mathematical model of the variation in bone geometry with age was developed which shows the reduction in cortical area in old age during which bone tissue was redistributed, so that neither bending stress in coronal plane nor torsional stresses were higher in old age than in young adulthood [20]. Morphometric study of the human pelvic using interpolation technique was performed for the analysis which is based on the Reynolds's to determine significant parameters for each class of pelvic [7]. Then structural behavior of the pelvis during lateral impact using finite element method was analyze which suggested that the anterior structure of pelvis are the most sensitive region, the FEM method determine the energy absorbing capability of the pelvis for lateral impact loading [18]. Experimental side impact test on twelve fresh frozen cadaveric pelvis using drop tower test has been done which is the first evidence to suggest that bone mass density (BMD) may be useful in the assessment of pelvic fracture risk in automotive side impact [10]. Then after developed a realistic 3D pelvis for finding out the stress pattern of the pelvic bone during normal walking specially in the area around the pubic ramus and acetabular cavity. It shows the variation of stress in pelvic bone during normal walking considering all active muscles [25]. Subject specific FE model of the pelvis is used to estimate the bone geometry, location dependent cortical thickness and trabecular bone elastic modulus using strain gauges for development, validation and sensitive studies [3]. Eleven impactor test on isolated pelvic bone have been individually simulated and corresponding mechanical properties and its range of variation determined [12]. The 3D joint potential contact area was obtained from the anterior- posterior radiograph of a subject and the actual contact area and pressure distribution in eight activities of daily living were calculated [14]. In order to define the solid geometry of pelvic bone an anatomic model of left hemi pelvis was constructed with inclusions of muscular and ligamentous boundary condition. Laser topography was carried out using a 3D laser scanner with an accuracy consisting of laser strip sensor, positioning arm and desktop PC. Striking difference in the stress-strain field observe in cortical bone in particular region are found [6]. Cohesive finite element modeling of age related toughness loss in human cortical bone was performed, the results indicated that contrast on initial toughness. The finite element simulation of crack growth in compact tension (CT), specimen successfully capture the rising R-curve in close correspondence with the experimentally observed decrease in term of percent (about 14-15) per decade. The finite element simulation result shows a decrease of 13 percent in R-curve slope per decades.[4]. For auto generating accurate FE model of femur and pelvis, the sparse CT data base used, the model use high order cubic Hermite element which have the advantage of capturing complex geometry using few element [27]. Biomechanical analysis of hard tissue and injury using new full finite element sub models for pelvis, the lower extremities and the upper extremities were constructed in which hard tissue modeled in the pelvis region included lumber, sacrum and coccyx, ilium, ischium, pubis, symphysis and acetabulum [17]. The full pelvis model was validate against measured force time impact responses from drop tower experiment to study biomechanical responses of symphysis during the experimental impact [30]. Developed and validate a patient-specific finite element models of hemi pelvis generated from sparse CT data set, in which three cadaveric embalmed pelvis were strain gauged using five rosette strain gauges and used in mechanical experiments. Material properties for cancellous bone were obtained from the CT scans and assigned to the FE mesh using a spatially varying field embalmed inside the mesh, while materials used in the model were obtained from literature [28]. Static and dynamic three-dimensional finite element analysis of pelvic bone was performed in which it was found that under the forced impact loading condition an overlapping behavior was noticed, whereas for free fall the normalized von-misses stresses behavior was found to nonlinearly differ [22]. Finite element development of child pelvis with optimization based material identification was made in which the pelvic bone geometry was reconstructed from a set of computed tomography images, and hexahedral mesh was generated using a new octree based meshing technique [19]. Computer aided diagnosis of risk state in human pelvic bone was performed using QCT, in which result suggested that when decreasing of bone mass appears in individual region only the stresses decrease at the beginning and next increase while the bone mass still decrease [1]. Numerical simulation of osteoporotic change in human pelvic bone was obtained using Dual energy X-ray absorptiometry (DEXA) and quantitive computed tomography (QCT). The study is to raise the problem of osteoporotic changes in human pelvic bone. The changes was modeled in form of establishing material property obtained from QCT [5]. Analysis of synthetic human pelvis loading rig for static and dynamic stress was performed , the device can be interfaced with a usual loading machine to preserves the anatomy of hemi pelvis to allows the simulation of all physiologic activities [11].When decreasing of bone mass appears in individual region only the stresses decrease at the beginning and next increase while the bone mass still decrease [31]. Model-based tissue injury criteria and a tool to predict occupant KTH injuries subject to different postures and loading rates. Knee-thigh-hip (KTH) a high rate impact more likely generates a fracture at the femur shaft; and the impact at a lower rate more likely fractures the hip-joint [32].Understanding the forces that cross the hip and the details of the anatomy leads to a better understanding of some of thefailures of the past and gives credence to current and future solutions[33]. Computed tomography images of a standard composite pelvis were used to create the three-dimensional finite-element intact pelvis model. Based on the intact model, finite-element models simulating the modified and Bernese periacetabular osteotomy were created[34].The use of contact hip stressmeasurements in orthopedic clinical practice is still in its experimental phase[35].Developed an approach starting from computed tomograms of thepatient and corresponding CAD-models of the implant. The algorithm is aimed atpredicting the stress and strain states in the surrounding bone stock and in the implant itselfand has the potential to predict relative micro motion[36]. CT scans of 38 non-pathologic individuals were analyzed. Functional orientation was computed as the density-weighted average of the acetabular surface normal based on surface density maps[37].Modeling and Simulation of BiomechanicalSystems - An Orbital Cavity, a PelvicBone and Coupled DNA Basespresented the results of stress and strain analysis of an orbitalcavity[38].A combination of computational models andtheoretical methods have been developed and used to study the contact of hip resurfacing devices under normal/central and edge loading conditions. The techniques have been developedand the solutions are based on using the finite element method[39].

III. CONCLUSION

In this study, a literature review was conducted to identify recent finite element models of human pelvis. On ground of geometrical model, numerical model of pelvic bone is performed using finite element. The mechanical behavior of pelvis model was compared to experimental data of impactor test on cadaver pelvises. Various loading system has been introduced for pelvis, most of these was designed in order to simulate specific loading condition. Biomechanical properties of pelvic joints are also compromise in relation to their ability to withstand increased compressive and tensile forces, torque and shear stress. The biomechanical alterations caused by the adapted posture, produce functional alteration of articular motion and the supporting structures. Additional findings of the literature review indicate that the visible human project data can be used to develop a finite element of human pelvis with an acceptable level of confidence compared to other database. Information from QCT can be helpful for researching progress of osteoporosis in individual clinical case. Creation of numerical model base on radiological data increasing its conformance to real condition, quality obtained results depends on amount of information gathered in database. This information may augment traditional evaluation method that determine static or dynamic loading. The value of this study, therefore is to enable doctors to better understand and treat problems. Still some knowledge gaps is there regarding the biomechanical tolerance and behavior of various region of pelvis under dynamic loading such as in heavy impact. So some more research is needed in order to optimize protection devices and car structure with regard to the security of occupant. This knowledge is also important for designing improve implant devices and crash dummies

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