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Review Paper on “Spine Biomechanics: An Overview”

Pallavi Pasnur[1]* Amala D. Bilapate[2]

[1] Assistant Professor, Civil Engineering Department, JSPM’s ICOER, Wagholi, Pune, Maharashtra, India

[2] PG Research Scholar, Civil Engineering Department JSPM’s ICOER Wagholi, Pune, Maharashtra, India

Abstract – This article reviews the many theoretical and practical simulation research reports on the spine biomechanics with the help of musculoskeletal system. Cervical spine is the frequent site for injury in the column of spinal cord. It is difficult to co-relate the theoretical concepts of spine biomechanics and empirical data due to their dynamism and complexity of their mechanical response. We can better explain the biomechanics of spine with the help of mechanics or structural system which are mainly compressive or tensile in nature. FE analysis is applied for the simulation of different types of clinically relevant situations. With the help of FE model, researcher can make a better decision before applying more extensive tests which are costly. And by this we can go for the simulation of 2D as well as 3D analysis.

Keywords: Spine biomechanics, SCI, Biomaterials, FE analysis.

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1. INTRODUCTION

Biomechanics is the study of movement of living things using the science of mechanics. And mechanics is the branch of physics that is concerned with the description of the motion and how force creates motion. Biomechanics mainly consists of musculoskeletal system which is the combination of bones, joint, muscles and related connective tissues. On the basis of kinesiology biomechanics is classified as kinematics and kinetics. Kinematics is further classified as qualitative analysis and quantitative analysis. Qualitative analysis is carried out to predict the behavior of the muscles or muscular activity for a particular phase or period. It is applicable in sports or exercise biomechanics. Electromyography is useful for it. It is nothing but the recording of electrical activity of the muscular tissues. And quantitative analysis is carried out to study the pattern of the behavioral variation of the musculoskeletal system. It is done by observing the growth of people and their musculoskeletal system. Factors considered for the kinematic analysis are flexion, extension, lateral flexion and rotation. Kinetics includes the study of different forces acting on the musculoskeletal system such as gravitational forces, joints influenced by the external forces, muscle forces. Factors considered for the kinetic analysis are axial compression, bending, torsion and shear. It is further classified as statics and dynamics. Static analysis is used for non-moving, slow moving or constant velocity systems whether in dynamic analysis used for systems under acceleration.

1.1 Spine Biomechanics:

Spine biomechanics is the study of movement of cervical spine which is mainly influenced by different loading conditions. Human spine consists of cervical (7V), thoracic (12V), lumbar (5V), sacrum (5V) and coccyx (4V) with 33 bones shown in figure 1, where V stands for Vertebrae as

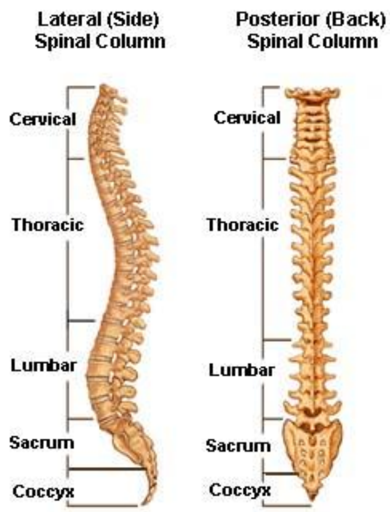

Figure 1: Spine biomechanics: (Source: Anonymous)

Different forces are acting on spine such as body weight, tension in the spinal ligament, tension in the surrounding muscles, intra-abdominal pressure. The major form of loading is axial. There is an increase in compression with the increase in spinal flexion and still increases further with a slouched sitting position. Cervical spine is the frequent site of injury.

1.2 Spinal cord injury

SCI means spinal cord injury which can happen at any place along the spinal cord. It is the consequence of harm to cells in the spinal cord and causes lost correspondence between the mind and the parts of the body beneath the damage. Impacts of SCI may incorporate low blood pressure, powerlessness to manage pulse adequately, lessened control of body temperature, failure to sweat beneath the level of damage and constant agony. Different vertebrae’s of spinal cord has following respective injuries:

C1: Atlas: It is fused to vertebrae C2

C2: Axis: Injury to C1 & C2 can result in a loss of many functions including the ability to breathe.

C3: Injury to C3 causes pain, tingling and sometimes numbness in the arms, neck and head.

C4: Cervical vertebrae: Injury to C4 causes total loss of use of four limbs.

C5: Injury to C5 also causes quadriplegia with some shoulder and sometimes with elbow function.

C6: Injury to C6 too causes quadriplegia with shoulder, elbow, and wrist function.

C7: Injury to C7 also causes quadriplegia with all above & some hand function.

C8: Injury to C8 causes quadriplegia with normal hand weakness.

T1 to T6: paraplegia is occurred, which is of loss of function below mid chest.

T1 to T8: injury to this causes decrease in abdominal muscle control.

T6 to T12: Paraplegia is of type loss of function below the waist.

T9 to T12: dysfunction of the bowel and bladder.

L1& L2: damage to the tip of the spinal cord.

L2- L5: causes osteoarthritis.

S1- S5: Injury to sacral region causes motor vehicle accidents, trauma, falls, birth defects, degeneration and osteoporosis.

1.3 Biomaterials:

A biomaterial is any substance that has been manufactured for the interaction of biological systems for a medical purpose of a therapeutic (treating, augmenting, repairing or replacing a tissue function of the body) or a diagnostic one. The required mechanical properties for the biomaterials are hardness, tensile strength, elongation fracture resistance and fatigue strength. Following are the biomaterials which are used for the manufacturing of the implants: stainless steel (SS), cobalt- chromium (Co-Cr) alloys, titanium and titanium (Ti-Ti) alloys, uncemented implants, tantalum, polyethylene and PMMA (Polymethylmethacrylate) cement. A Ti & Ti alloy is the best biomaterial as it is biocompatible and haemocompatible (there will be no change after implanting it inside the body).It has high tensile strength. It is nontoxic, possessing lower density and low modulus of elasticity. We can go for the implant fixation without using PMMA cement.

i. **Stainless steel (SS):** 316 L: It is used as a temporary implant such as screws and plates.

ii. **Co- Cr alloys:** It is tough, hard, having high tensile strength, corrosion resistance, less wear effect and possesses better compatibility. Sometimes it is added with Molybdenum (Mo) which results increase in the strength of this type of alloy. It is also used with Titanium (Ti). It is generally used in designing of metal knee implant. But use of this metal implant becomes lesser as many patients’ complaint allergic reactions.

iii. **Ti – Ti alloy:** These are further classified on the basis of type of alloys which are alpha, beta and gamma. It depends on the modulus of elasticity. Beta phase exhibits much lower modulus than that of the alpha phase. There will be no change after implanting it inside the body. Due to its property of biocompatibility and homocompatibility it is termed as a best biomaterial. It also has corrosion resistance property. It has high tensile strength, less wearing effect, non-toxic and possessing lower density with low modulus of elasticity. It is compact in nature.

iv. **Uncemented implants:** These are certain implants which directly being fixed to the bone surface, so as bone growth on the surface will increase as the fixation site.

v. **Tantalum:** It has excellent physical, SCI means spinal cord injury which can happen at any place along the spinal cord. It is the consequence of harm to cells in the spinal cord and causes lost correspondence between the mind and the parts of the body beneath the damage. Impacts of SCI may incorporate low blood pressure, powerlessness to manage pulse adequately, lessened control of body temperature, failure to sweat beneath the level of damage and constant agony. Mechanical and properties showing flexibility, corrosion resistance, tensile strength and biocompatibility.

vi. **Polyethylene:** the tibial and patellar components in knee replacements are made up of this.

1.3.1 Properties of biomaterials:

Table 1: Properties of biomaterials:

Material	Density (gm/cm3)	E (N/mm2)
Co - Cr alloy	8.5	7-30
316 L SS	8	230
CP (commercially) -Ti	4.51	200
Ti – 6A14U	4.40	106
Bone	1.50 (kg/m3)	100000

(Source: Anonymous)

Requirements of biomaterials owing to following mechanical properties: Hardness, tensile strength, elongation, fracture resistance, fatigue strength, modulus of bones (4 to 30 GPA).

Requirements of biomaterials owing to following non - mechanical properties:

i. High corrosion resistance

ii. Biocompatibility: It is the ability to exist in contact with tissues of the human body without causing an unacceptable degree of harm to the body.

iii. High wear resistance: It gives compactness to implants.

iv. Osseo integration: It is the process of formation of new bone and bone healing. Surface chemistry, roughness and topography are all parameters that influence both the Osseo integration and biocompatibility.

1.4 Stress - strain analysis:

The tensor behavior is studied by using the constitutive equations determining the stress - strain relation in the material in order to study the mechanical behavior of the intervertebral disc. The disc is observed within the motion segment. The motion segment involves two neighboring vertebrae and the intervertebral disc between them that connect them both.

For example: A C0-C7 FE model (nonlinear, geometrically similar) was developed for the simulation of movement of the head and cervical spine under both static and dynamic conditions (flexion, tension, axial rotation and lateral bending). It was done by applying 1.0Nm load on it with the assumption of fully constrained body. With the help of experimental results of simulation, model predicted the nonlinear moment rotation relationship of human cervical spine.

2. REVIEW OF LITERATURE

i. **Qing Hang Zhang et.al** contemplated limited component investigation of minute pivot connections for human cervical spine. A nonlinear C0– C7 FE model of head and cervical spine in light of the actual geometry was produced. The model anticipated the nonlinear minute revolution relationship of human cervical spine [1].

ii. **Jozef Sumec et.al** studied 3D FEM analysis of human lumbar spine for extreme positions. In this, researchers prescribed the techniques of the biomechanics with the help of modeling and 3D FE analysis of spine. From this researcher stated that, obtained results are applicable for the preliminary diagnostics [2].

iii. **Musculoskeletal biomechanics BIOEN 520, ME 599R: Session 12B: biomechanics of spine**: In this session researcher discussed case study based on shear testing with the help of spine stimulator. They have also discussed pediatric spine biomechanics.

iv. **Hai Yaoa et.al** considered finite-element analysis of three-dimensional (inhomogeneous) physical signs and solute transport in human intervertebral disc under axial compression**.** This study is useful for the better understanding of disc biomechanics, disc nutrition, and disc mechanobiology [4].

v. **Haiyun Li et.al** examined intervertebral disc biomechanical analysis using the finite element modeling based on medical images. A 3D geometric model of the intervertebral and lumbar disc has been introduced. The stress and strain distribution and deformation of the spine can be studied from the simulation data [5].

vi. **Joanna Kaminska Danuta Roman-Liu et.al** studied differences in load due to different positions of the lumbar vertebrae and action of external load. According to results of researcher owing to computer calculations, it is confirmed that stresses and compression forces in intervertebral discs increases with an increase in the load force. These values were significantly larger in the bent forward posture than in the erect posture [6].

vii. **N. Toosizadeh et.al:** A geometrically exact, nonlinear FE model of C0– C7 was produced. This examination gives confirmation of higher cervical spine interior loads in non-impartial head stances [7].

viii. **Zhitao Xiao et.al** examined a non-linear finite element model of human L4-L5 lumbar spinal portion with three-dimensional solid element ligaments. The simulate relationship curves between generalized forces and generalized displacements of the non-linear finite element model are contrasted and the in vitro exploratory outcome curves to check non-linear finite element model [8].

ix. **Mohammad haghpanahi et.al** studied how to generate FE model of the cervical spine, investigating the role of the muscle forces in flexion or extension. Utilizing a biomechanical model and an optimization algorithm, analysts built up connection between muscle forces and rotation of the neck for static state [9].

3. AREAS OF STUDY AND RESEARCH:

Biomechanics has wide area of research and development. It may be used in the following areas:

1. Sport and Exercise Science
2. Ergonomics
3. Equipment Design
4. Locomotion
5. Orthopedics-Rehabilitation-Physiotherapy, Occupational Therapy
6. Prosthetics and Orthotics
7. Motor Control
8. Computer Simulation

4. FUTURE SCOPE:

The future work will be focused on the combined load, as an eccentric loading and torsion. Moreover, as the physical properties changes with the age of its holder, it will be worth to involve time dependence into the model.

5. METHODOLOGY

Simulation is done with help of biomechanics models (in vitro, in vivo, FE). FE models are widely used to yield estimates of parameters that are not commonly analyzed in detail in in vitro and in vivo studies. In dynamic type of FE analysis, models consists of a series of vertebrae (as rigid bodies) connected by ligaments. And it also consists of discs modeled on springs. These models can effectively predict the gross intervertebral response under loading conditions. And in static type of FE analysis the study of simulation is in detailed manner. It is focused on spinal materials and its geometry. These models while simulation predicts about the internal stresses, strains and biomechanical responses under complex loading conditions.

Material properties used for various components in model are Young's modulus and Poisson's ratio.

6. CASE STUDIES

- For example, variables such as the displacement of a ball, the velocity of a skater and the acceleration of the free leg all describe motion and are kinematic variables.
- Case study (Source: Ref 3): Biomechanical testing:

6.1 Following points are discussed in this case study:

i. Reviewed the types and functions of joints

ii. Discussed which mechanical properties of joints are generally of interest and why

iii. Examined the joint disease and how abnormal mechanics might play a role.

iv. Discussed full joint replacement system.

6.2 How the mechanical properties of spine are tested:

i. Establish mode of testing. (Tension, bending)

ii. Obtain tissue sample. (Type, age, gender samples)

iii. Prepare test specimens.(Dissect, wire, potting)

iv. Set up testing apparatus and fixturing. (Test frame, fixtures, measurement devices, DAQ)

v. Choose test parameters. (Preconditioning, loading rate, sampling rate, filtering)

vi. Run tests.

6.3 Spine stimulator:

It is used for shear testing as a testing tool. It consists of MTS piston, SNM torque motor, anterior extensometer, rotating axle or potting jig, posterior extensometer, MTS force plate as shown in figure 2

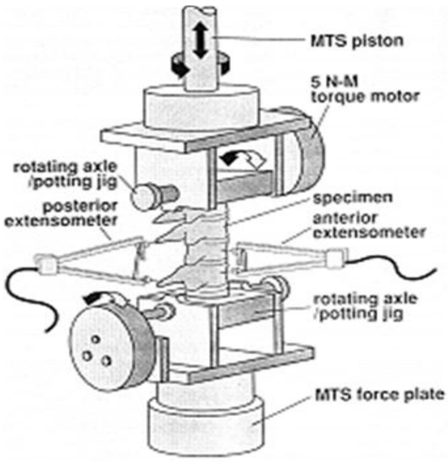

Figure 2: Spine stimulator:

(Source: Ref. 3)

To perform the different tests we required the mechanical as well as non- mechanical properties. (Table 2)

Expected mechanical properties are as follows:

Table 2: Expected mechanical properties:

Stiff/ Failure	Cervical	Thoracic	Lumbar
Flexion	0.3-0.5/15-20	1-3/30-40	2-3/75-200
Extension	0.5-1/16-21	2-3	2-3
Lateral bending	0.5-1/24-28	2-3	2-3
Torsion	1-2	2-3	2-3

(Source: Ref. 3)

Stiffness: N-m/degree, Failure load: N-m

7. CONCLUSION

Following are the few conclusions from the investigation of above analysts:

- The thoracic region is subjected to increased compressive forces in comparison with the cervical region because of the greater amount of body weight that needs to be supported and the regions kyphotic shape.

- Lower cervical spines are less flexible than the upper one.

- There is increase in the compression with increase in the spinal flexion and increases still more with a slouched sitting position

- According to results of the computer calculations researcher has been confirmed that stresses and compression forces in intervertebral discs increased with an increase in the load force and that they were significantly larger in the bent forwards posture than in the backward posture.

- Owing to researchers results obtained from shear testing we can draw different plots.

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Corresponding Author

Pallavi Pasnur*

Assistant Professor, Civil Engineering Department, JSPM’s ICOER, Wagholi, Pune, Maharashtra, India

E-Mail – pallavi.vangari1@gmail.com