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Segmentation of Human Vertebral Spine -FEA Analysis

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Abstract

Back pain is one of the most common health problems facing people today. It is the second most common reason for a doctor's visit, behind only to the common cold. Billions of dollars are spent annually on treating back pain, which is also a very common cause of disability. More than 90% of people will experience an episode of debilitating back pain at some point in their lifetime. Once the chronic disc problem has been diagnosed, the conservative treatments like: specific rest, friction force medical aid or physiotherapy and exercise are followed. When correctly diagnosed, an excessive amount of medical/surgical treatments can be avoided. The aim of the study is to generate a mesh model and numerically simulate the biomechanical characteristics of the human spine, namely two vertebrae (L4 and L5) and inter vertebrae disc using finite element analysis (FEA) technique. In this process the bony areas of every MRI scanned image is segmented and the boundary lines are stacked into a smooth surface. Additionally, the technique generates the quantity mesh exploitation linear unit that is used to process the mesh for agreement. Moreover, L4 and L5 with disc were considered as linear materials with the exception of the ligaments. The contact behaviour of the two bones, simulation of disc and obtained displacements and stress describe about the pre-operation of human lumbar spine. The results depict that the potential fracture of the considered patient with respect to displacements. In this paper the implementation of bilateral filter technique is discussed . Using various edge detection algorithms namely, Canny edge detection, Sobel edge detection, Prewitt edge detection and Roberts edge detection, the results were compared. Among them, spine Canny edge detection algorithm produced effective output using MATLAB estimating the following parameters like total deformation, normal elastic strain, normal stress. With the help of these parameters, the human spine model was analyzed using the simulation software ANSYS. The implementation has done with MATLAB, whereas the stress and strain have been found at the plate bone of aspect joint of L4 and L5.

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I. INTRODUCTION

The human back is composed of a complex structure of muscles, ligaments, tendons, disks, and bones, which work together to support the body and enable us to move around. The segments

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of the spine are cushioned with cartilage-like pads called disks.

Structural problems

A number of structural problems may also result in back pain.

Ruptured disks: Each vertebra in the spine is cushioned by disks. If the disk ruptures there will be more pressure on a nerve, resulting in back pain.

Bulging disks: In much the same way as ruptured disks, a bulging disk can result in more pressure on a nerve.

Sciatica: A sharp and shooting pain travels through the buttock and down the back of the leg, caused by a bulging or herniated disk pressing on a nerve.

Arthritis: Osteoarthritis can cause problems with the joints in the hips, lower back, and other places. In some cases, the space around the spinal cord narrows. This is known as spinal stenosis.

Abnormal curvature of the spine: If the spine curves in an unusual way, back pain can result. An example is scoliosis, in which the spine curves to the side.

Osteoporosis: Bones, including the vertebrae of the spine, become brittle and porous, making compression fractures more likely.

Kidney problems: Kidney stones or kidney infection can cause back pain.

The spine is divided into four each section and is referred by the letters.

Cervical (**C**): Neck sections, and Thoracic (**T**): Chest Lumbar (**L**): Lower back Sacral (**S**): Pelvis

Within each section of the spine, the vertebrae are numbered beginning at the top. These labels (letter plus a number) are used to indicate locations (levels) in the spinal cord. Along the length of the spinal cord, 31 pairs of spinal nerves emerge through spaces between the vertebrae. Each spinal nerve runs from a specific vertebra in the spinal cord to a specific area of the body. Based on this fact, the skin's surface has been divided into areas called dermatomes. A dermatome is an area of skin whose sensory nerves all come from a single spinal nerve root. Loss of sensation in a particular dermatome enables doctors to locate where the spinal cord is damaged. Three dimensional finite element models is developed using the magnetic resonance imaging (MRI) of the lumbar region L1- L5. The anatomical structure of the bone was clearly produced by numerical modeling which was mainly based on finite element method (FEM). It produces simulations stress and local distortions under various loading conditions. The justification of its uses in the field of orthopedics for the lumbar region is studied using finite element analysis technique. The estimation and organization of occupational low back complaints and back pains were studied. The biomechanical behavior of human bone is estimated by applying various boundary conditions. A vertebrae and a disc are the two segments which is called as a motion or movement segment of the spine. Experiments are made on the spine disk and are described. Edge detection algorithm is the major tool for obtaining accurate data from the images by providing their sketch and boundaries. Using Filtering techniques, the noises are detached from images and are enhanced. It is still difficult to detect the correct boundary in a noisy image. For pre- processing, the boundary discovery of the MRI-scanned image of the Spine, Canny Edge Detection algorithm has been proposed. A better result is produced using the Canny Edge Detection algorithm. Low back pain is a serious disease commonly referred to as lumbar degenerative disc disease (LDDD), mostly caused by aging and overloading. Such condition can be triggered using FE method. If not an advance stage, medical/surgical treatments can be avoided by applying conservative treatments like; specific rest, tractive force therapy or physical therapy and exercise. Volume mesh is generated followed by the processing of the mesh for conformance. The primary objective of this study is to design the model, generate meshes and simulate the biomechanical characteristics of the human lumbar spine, with two vertebrae (L4 and L5), and the inter vertebrae disc, by using finite element (FE) Method. The lumbar spine model of a real person is taken into consideration for analysis

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using MATLAB and ANSYS. The processes included the segmentation and smoothing of the bone of each MRI scan image with intervertebral disc, which are later modeled as linear materials with the exception of the ligaments [3]. The behavior of the two bones and the discs were simulated and with predictions of the dislocations and stresses on the lumbar spine. Comparison was performed in accordance with their result with different edge detection algorithm (Canny edge detection, Sobel edge detection, Prewitt edge detection and Roberts edge detection). From the experimental results it has proved that Canny Edge Detection algorithm is effective in edge detection of lumbar spine. Thus, best filter is selected with canny edge algorithm for 2D and 3D modeling.

1.1 Human spinal cord C1 to S5 vertebrae

The spinal cord is a bundle of nervous tissue. Spine cells continue from the medulla oblongata to the lumbar region of the vertebral column. The Central Nervous System (CNS) is composed of the brain and spinal cord and conveys all messages to brain and other parts of the body. Generally, spine bones are called as vertebrae. The arrangement of vertebrae is in a pile of coins fashion. Nerve tissues pass between the vertebrae arrangements. These vertebral regions of spine passes from the base of the skull to the pelvis [4]. There are 33 bones in the human spinal column. These 33 bones are segregated in following fashion: cervical region contains 7 vertebrae, thoracic region contains 12 vertebrae, lumbar region contains 5 vertebrae, sacral region contains 5 vertebrae and coccyx region contains 4 vertebrae. Based on the regions and positions the names are given to each vertebra. Stretching from the superior to the inferior, human spine have seven cervical vertebrae that are designated as C1–C7, twelve thoracic vertebrae that are designated as T1–T12 and five lumbar vertebrae that are designated as L1–L5. The other 9 bones of the spine are collectively called as sacral and coccyx regions. In which the sacral region has five fused vertebrae that are designated as S1-S5 and coccyx region has 3–5 vertebrae that is commonly called as tailbone.

1.1.1 Lumbar vertebrae

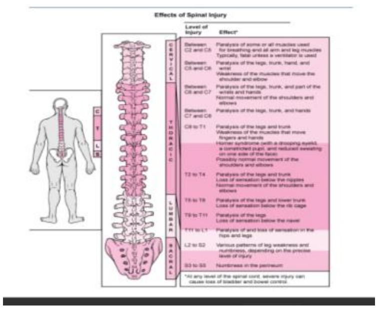
The **lumbar vertebrae** are, in human anatomy, the five vertebrae between the rib cage and the pelvis. They are the largest segments of the vertebral column and are characterized by the absence of the foramen transversarium within the transverse process (since it is only found in the cervical region) and by the absence of facets on the sides of the body (as found only in the thoracic region). They are designated L1 to L5, starting at the top. The lumbar vertebrae help support the weight of the body, and permit movement. . This naming is based on top-down approach of lumbar vertebrae [5]. They are situated in the abdomen and they are the segments of the detachable part of the vertebral column. shows the lateral view of the human lumbar spine and the lumbosacral junction. The components of lumbar spine: the body, the pedicles, the lamina, the spinous process, the inferior and superior articular processes, and then the transverse processes. The pedicles are biggest and vigorous to withstand the entire region of pedicle region. The lamina is small but strong and wide when it is compared to the first two vertebrae. It is smaller than cervical region but larger than the thoracic region and resembles in triangular shape. The spinous process is wide, dense and resembles in quadrilateral shape. The inferior and superior articular processes are anticipated in downward and upward direction emerged from the lamina and the pedicles joints. The transverse processes are extended and slim, and flat in the upper parts of three lumbar vertebrae. In the upper three vertebrae, they emerge from the joints of the pedicles and lamina, but in lower parts of two vertebrates they are in forward and spiral from the pedicles and posterior parts of the bodies.

1. 1.2.Sacral Vertebrae

There are 5 sacral vertebral bones. They are represented by the symbols S1 through S5 and are situated between the lumbar vertebrae and the coccyx (the lowest segment of the vertebral column). The sacral vertebrae are normally fused to form the sacrum. The main physiology of sacrum vertebrae is to withstand the weight of upper body into the legs. This sacrum region joins hip bones to form pelvis. The 5 vertebrae of sacral regions are named as S1, S2, S3, S4 and S5. As a result, the fusion of this sacral region tends to form the sacrum. The segment where the lumbar spine meets the sacral region, L5–S1, was prone as the area that causes degeneration and creates back problems. This region slightly from side-to-side and dorsal surface is curved and thinner than the pelvic and entire components of the sacrum are indicated at facies dorsalis.[1]

1.1.3 Coccyx Vertebrae

The **coccyx**, also known as the tailbone, is a small, triangular bone resembling a shortened tail located at the bottom of the spine. It is composed of three to five coccygeal vertebrae or spinal bones. The vertebrae may be fused together to form a single bone; however, in some cases, the first vertebra is separate from the others.



F Figure 1. Diagram depicts the segments of human spinal cord and its effects .

1.2 Biomechanics Model for Estimating Loads on Thoracic and Lumbar Vertebrae

Biomechanical models are commonly used to estimate loads on the spine during occupational bending and lifting tasks, as well as during common activities of daily life. Current models have focused on low back pain, and as a result have dealt almost exclusively with forces in the lumbar and sacrolumbar regions. Acute pain in the upper back and shoulders is a commonly occurring injury among industrial and service workers . Furthermore, vertebral fractures are most common at the mid-thoracic and thoracolumbar regions. Despite these injury patterns, little progress has been made toward understanding the loads applied to the thoracic spine during common activities. Existing biomechanical models of the thoracic spine have studied respiratory mechanics, scoliosis, and ribcage deformities (Andriacchi et al., 1974, Closkey et al., 1992, Kong and Goel, 2003, Loring, 1991), rather than forces applied to the thoracic vertebrae. Thus, a biomechanical model capable of estimating forces applied to thoracic vertebrae and exerted by surrounding trunk musculature may provide insights into the etiology of musculoskeletal disorders in this region. To project the 3D view of the spine model, following parameters, total deformation (TD), equivalent elastic strain (EES), maximum principal elastic strain (MaxPES), minimum principal elastic strain (MinPES), normal elastic strain (NES), shear elastic strain (SES), equivalent (von- Misses) stress (ES), maximum principal stress (MaxPS), minimum principal stress (MinPS), normal stress (NS), shear stress (SS) of the load from the lumbar spine are required [6]. Long-term vibration and cyclical properties may increase the stress in the spine which tends to result in anatomical changes and weakness in the tissue of discs and vertebrae. Shocking burden of the spine leads to disc and facet joints injury. Muscles help to safe guard the spine from excessive loading and activities. This guard functions only if the central neural system has adequate time to trigger the muscles.

2 FILTERING TECHNIQUE USED FOR HUMAN SPINE REGION

2.1 Image de-noising

Image de-noising is the traditional way of removing noise in image processing. Many methods, regardless of implementation, share the same basic idea–noise reduction through image blurring. The main goal of digital image processing is to acquire the image de-noising and to utilize the inhibition of linear white noised values that will create image corruption throughout its transmission or acquisition. Impulsive noise is usually found throughout the procedures of transmission, acquisition, storage and retrieval. The area unit detection is used to differentiate the corrupted pixels and also the uncorrupted pixels. The filtering method is used to process the corrupted pixels using the most suitable techniques. This method employed within the filters so as to gauge concerning the performance of remodel domain or spatial-domain[10]. Whereas considering certain spatial-domain filtering, area unit of image pixels are directly passed on the filtering method during this technique[11]. Meanwhile, the pictures ought to be, remodeled into the frequency domain 2-D image.

2.2 Median filter

The Median Filter is a non-linear digital filtering technique, often used to remove noise from an image or signal. Such noise reduction is a typical pre-processing step to improve the results of later processing (for example, edge detection on an image). Median filtering is very widely used in digital image processing because, under certain conditions, it preserves edges while removing noise , also having applications in signal processing. It basically uses a simple non-linear operator that substitutes the center pixel in the window with the median value of its nearby value. The median filters would adopt the moving window principle that is same as mean filter. The pixel size from 3 * 3 to 7 * 7 kernel of pixels is glanced over the pixel matrix of the complete image. Primarily, it measures the values of the median pixel in the window and then substitutes the middle pixel of the window with the measured median value. All the values in the pixel matrix from the surrounding neighborhood are measured at first, succeeding to form it into numerical order and later on, it substitutes the pixel being regarded with center pixel value.

$$P(X \le m) \ge 1/2 \;\&\; P(x \ge m) \ge 1/2 \qquad (1)$$

$$\int_{-\infty}^{M} df(x) \ge \frac{1}{2} + \int_{M}^{\infty} df(x) \ge \frac{1}{2}$$

(2)

To compute the inequalities, a Lebesgue–Stieltjes integral principle is employed. For an absolutely continuous probability distribution with probability f, the median has to satisfy the following condition;

$$P(X \le m) = P(X \ge m) - \int_{-\infty}^{m} f(x)dx = \frac{1}{2} \qquad (3)$$

Any probability distribution on R has at least one smallest median, but there may be chances of more than one median. In the results, if accurately one median exists, then it is termed as ‘‘the median’’ properly fixed; when the median is not uniquely fixed, then it is termed as—‘‘the median’’ off handedly fixed. The mean filter is a simple sliding-window spatial filter technique that substitutes the center value in the window with the normal mean of all the pixel values in the window. The window, or kernel, is usually square but can also be of any shape. The Median filter technique is processed mainly to reduce the image de-noising impact within the MRI scan pictures. The resultant of Median filtered pictures is applied on the different edge detection algorithms namely, Canny edge detection, Sobel edge detection, Prewitt edge detection and Roberts edge detection.

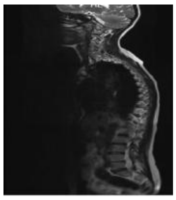


Figure 2. Median filter

2.3 Bilateral filter

Bilateral filter can be extended to treat more general reconstruction problems such as image restoration, image scaling, super-resolution, and more .An unknown signal represented as a vector goes through a degradation stage in which a zero-mean white Gaussian noise is added to it. The result is the corrupted signal given by

$$I^{bilateral}(x) = \frac{1}{W_V} \sum_{xe\Omega} I(x_f) f_r(\|I(x_f) - I(x)\|) g_X(\|x_f - x\|)$$

(4)

Where $I^{bilateral}$ denotes the bilateral image and I denotes the original image. Bilateral filter is processed mainly to reduce the image de-noising effect within the MRI scan pictures.

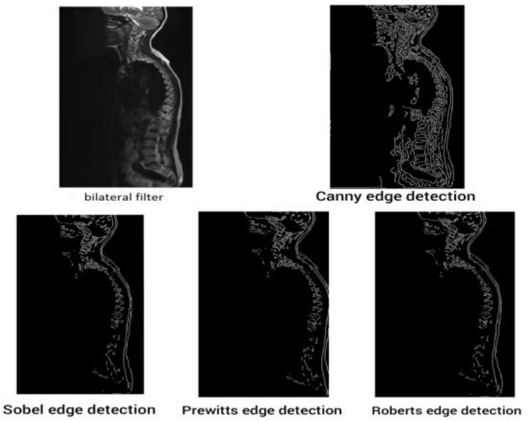


Figure 3.Bilateral filter and its edge detection

3 VARIOUS EDGE DETECTION TECHNIQUES USED FOR HUMAN SPINE

3.1 The Canny edge detection

The Canny algorithm finds application as an optimal edge detector algorithm [7]. Based on a following set of criteria

it can

1. Encounter the most edges by reducing the error rate.

2. Mark edges nearer to the real edges to exploit localization

3. Mark edges once for given edge which exists to get a least response.

According to Canny edge algorithm, the parameters detection has been carried out in the spine images

Step 1 The average magnitude is evaluated by

$$M(1,2) = \frac{1}{M}\sum_{(1,2)}^{n}\sqrt{M_x(1,2)^2 + M_y(1,2)^2} \qquad (5)$$

The optimum filter that satisfies all the above three benchmarks can be proficiently estimated using the first derivative of a Gaussian function.

$$GF(i,j) = \frac{1}{2\Pi\sigma^2} e^{\frac{i^2+j^2}{2\Pi\sigma^2}}$$

(6)

Step 2 The density of the edge length is calculated by

$$L(1,2) = \frac{c(1,2)}{\max c(1,2)}$$

(7)

Where c(i,j) is the number of connected pixels at each position of pixel.

Step 3 The initial position of map from summation of density of edge Length and average magnitude is derived by

$$P(1,2) = \frac{1}{2(M(1,2)+L(1,2))}$$

(8)

Step 4 The threshold of the initial position map is obtained by.

$$P(1,2) \succ T_{\max}$$

Then P(1, 2) is the initial position of the edge following and then obtained that the initial position by setting T_{Max} to 98% of the maximum value.

3.2 Sobel edge detection algorithm

The Sobel edge detection algorithm is utilized for generating a 2D spatial gradient calculation on spine image. It uses the Sobel operator to find the 2D gradient. This algorithm is on Robert Cross operator principle. With this we can estimate the high spatial frequency edges found on the spine images which is also possible for grayscale images. Additionally, the expected gradient magnitude is found using this Sobel operator. This Sobel operator makes use of a pair of 3* 3 convolution kernels. Each kernel is at an angle of 90 degrees.[1]

The gradient magnitude is given by

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$$G = \sqrt{G_x{}^2 + G_y{}^2}$$

Stereotypically, an approximate magnitude is computed using:

$$|G| = |G_x| + |G_y|$$

By this computation become faster. The orientation angle of the edge (comparative to the pixel grid) giving rise to the spatial gradient is given by:

$$\theta = \arctan\left(\frac{G_x}{G_y}\right)$$

Step 1: Receive the MRI scan noisy spine Disc as input image

Step 2: Put on mask Gx, Gy to the noisy Spine Disc input image

Step 3: Put on Sobel edge detection algorithm and the gradient

Step 4: Covers the manipulation of Gx,Gy uniquely on the input image

Step 5: Combine results to discover the absolute magnitude of the gradient

Step 6: The absolute magnitude that extracted is the output edges.

3.3 Prewitt edge detection

The Prewitt edge detection algorithm is the greatest choice for measuring the magnitude and orientation of spine image edges. The drawback of many edge detection algorithms being their time taken to estimate the magnitude and orientation of an image is more. But prewitt edge detection algorithm directly estimates the orientation values from the kernels using the magnitude in x and y directions of an image. Apart from the usual eight orientations estimations, the Prewitt edge detection algorithm can also estimate beyond the suggested level but with less accuracy. While the gradient based edge detector detects only 3*3 neighborhood orientation fashion this algorithm detects in all eight possible directions including their convolution masks are calculated. Within that one convolution mask is then selected and named with largest module.

At each point in the image, the resulting gradient approximation can be combined to give the gradient.

$$G = \sqrt{G_x{}^2 + G_y{}^2}$$

Using this information, we can also calculate the gradient's direction:

$$\theta = a\tan 2(G_x + G_y)$$

Step 1: Receive the MRI scan noisy spine disc as input image

Step 2: Insert mask Gx, Gy to the noisy spine disc input image

Step 3: Derive Prewitt edge detection algorithm and the gradient

Step 4: Cover the manipulation of Gx, Gy separately on the input image

Step 5: Combine results to estimate the absolute magnitude of the gradient

Step 6: The absolute magnitude that extracted is the output Edges

3.4 Roberts edge detection algorithm

The Roberts Cross operator performs a simple, quick to compute, 2-D spatial gradient measurement on an image. It thus highlights regions of high spatial frequency which often correspond to edges. In its most common usage, the input to the operator is a grayscale image, as is the output. Pixelvalues at each point intheoutput represent the estimated absolute magnitude of the spatial gradient of the input image at that point.

These kernels are designed to respond maximally to edges running at 45° to the pixel grid, one kernel for each of the two\perpendicular orientations. The kernels can be applied separately to the input image, to produce separate measurements of the gradient component in each orientation (call these *Gx* and *Gy*). These can then be combined together to find the absolute magnitude of the gradient at each point and the orientation of that

4 FINITE ELEMENT SIMULATION ON THE REAL DATASET

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4.1 Mesh generation

Mesh generation is the practice of creating a mesh, a subdivision of a continuous geometric space into discrete geometric and topological cells. Often these cells form a simplified complex. Usually the cells partition the geometric input domain. Mesh cells are used as discrete local approximations of the larger domain. Meshes are created by computer algorithms, often with human guidance through a GUI , depending on the complexity of the domain and the type of mesh desired. The goal is to create a mesh that accurately captures the input domain geometry, with high-quality (well-shaped) cells, and without so many cells as to make subsequent calculations intractable. The mesh should also be fine (have small elements) in areas that are important for subsequent calculations. Using ANSYS software, a model is segmented into a numeral finite surface. Hence, this finite surface is transformed into volumes. Thus obtained volumes help us to form three- dimensional (3D) meshes, which can then be used for simulation. This approach of analysis is termed " meshing". Mesh is a distinct illustration of the geometrical model. It labels the elements or cells on which the problem is resolved under various boundary conditions that are applied on the spine model. The obtained meshes are termed " grid generation". It functions primarily based on the distribution points in volume of a physical region. The exercise of polygonal or polyhedral generating mesh estimates a geometric model with different shapes like triangle, tetrahedral, and so on . The discovery of mesh quality is mainly used for numerical applications in the field of science and engineering. Grid density, adjacent cell length/volume ratios, tetrahedral versus hexahedral and boundary layer mesh are analyzed using mesh quality. Using 2D and 3D Finite Element Method (FEM), triangular and tetrahedral mesh on surfaces and solids are developed. This describes the meshes of the numerical simulation and analysis using the real medical data set model.

4.2 Generating mesh

Surface triangulation FE method is used with Surface triangulation to produce surface mesh. This surface mesh resembles between the geometry model and the volume mesh. The input for the surface mesh can be obtained in various ways and each tends to a different problem of surface triangulation. The surface mesh is developed using the ANSYS software which

be smooth and derived by using implicit equations. Computed high quality surface mesh using MRI scan of a real person is widely used in application like in geometric modeling, computer graphics and finite element methods

4.3 Meshing

Finding the geometrical parameters of spine is an ultimate goal of subject-specific finite element model (FEM) approach. By this approach we can find the geometrical parameters which aid in the development of finite element mesh. Finally, the detailed explanation to be given for each obtained material properties corresponding to their subject. To achieve the subject-specific meshes of the spine, direct conversation approach is employed [4]. Using the computed image densities of the image, the material behaviors are defined. Using element-by-element approach, the material behaviors are defined individually.

5 RESULTS AND DISCUSSION

After computing the efficiency of the proposed method, they are displayed in graphical representational way. In image segmentation of various methods like median filter with various edge detection algorithms such as Sobel, prewitt, Robert and Canny edge detection algorithm were compared. The comparisons showed that canny edge detection algorithm clearly identifies the edges. On comparing various filtering technique like Bilateral filter gives better results with different edge detection algorithm.

5.1 Load displacement

The loads were subjected on the L1 superior surface in following measurements. The L1 superior surface tolerates a 686 N load in which a healthy person weighted 70 kg, stands straight in relaxation state. However, the tolerance level increased to 2500 N when a data lifts a load with two arms extending straightforward. The heavier

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the load lifts the more L1 superior surface tolerates. When the heavier load forces on the L1 superior surface tolerates with the results of load displacement behavior in axial compression. The withstanding tolerance level on model demonstrates that the vertebral bone has flexible biomechanical physiognomies. The implementation results at an angle of 90 as shown below. The obtained result displays the potential injury of the considered patient based on their bone displacements. It was established at the spinous process of L4. In the meantime the stress was identified at the lamina bone of facet joint of L4 and L5 [9]. The result of post-operation geometry model depicts that the distance between the two points of spinous process implanted has the same measurement in both geometries. If greater load is applied on the spine bone, then the stress concentration may be greater in pedicle region As a result, the displacement of L1 vertebral bone initiated by compressing the vertebral body and the superior articular processes in downward direction. Accordingly, the movement of vertebra due to the applied load and restraints subjected on the model creates the high stress in the pedicle region of spine. The result clearly implies that a high stress acts on the pedicle region of spine due to applied loading conditions. Besides, particularly an upper body of vertebral bone of spine was affected to an extent. Because those areas indicate higher values of stress which are estimated from the comparative results

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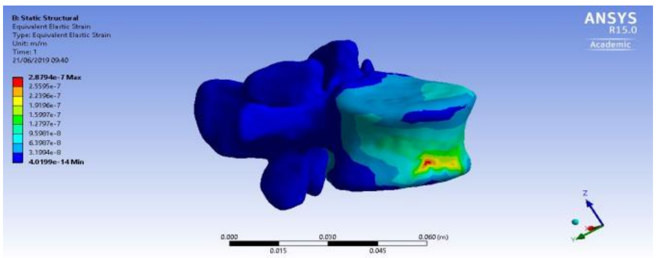

Figure 4. Strain

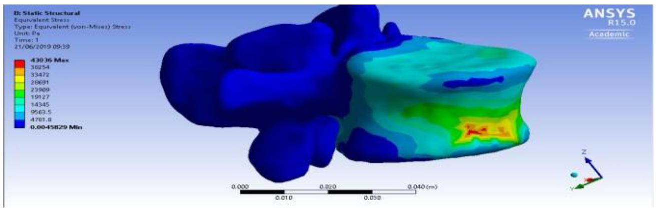

Figure 5. Stress

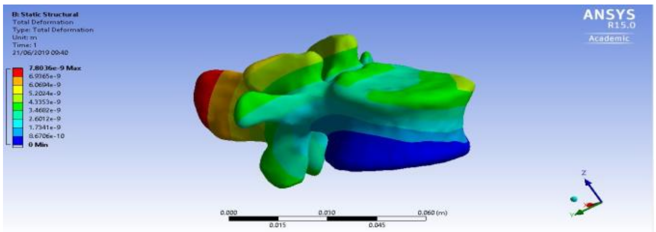

Figure 6. Deformation

5.2 Conclusion

Our approach works on two assumptions on the task of spinal column segmentation. First the vertebrae is separated from the background using various segmentation process out of which canny edge detection gives better result. Then the segmented vertebrae is modeled using ANSYS to find out performance of spine under various load conditions.

5.3 Future Scope

The spine Image is very easily damaged for all age people so apart from segmentaion if we model the segmented image using any modeling tool like ANSYS ,COSMOL we can get clear idea of the abnormal area and the load can be applied to that area can be calculated easily . Here to start with ANSYS is applied for any spinal bone image. Hence in the future we can apply this tool for our segmented area for treatment of abnormal sections.

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