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REACTION AT THE INTER-VERTEBRAL DISC DUE TO VARIATION OF POSTURE OF LUMBAR SPINE AND THE CONSEQUENCES ON THE LOWER BACK PAIN

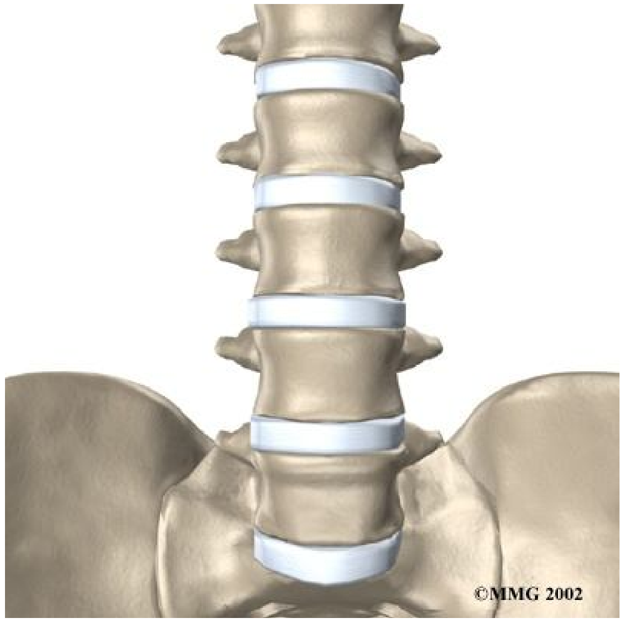
[1]M.Y. Mafuyai, [2]B.G. Babangida, [3]E.S. Mador, [4]D.D. Bakwa and [5]Y.Y. Jabil
[1,4,5]Department of Physics, University of Jos, Jos, Plateau State, Nigeria.
[2]Department of Mathematics, Kaduna State College of Education, Gidan Waya, Kaduna State, Nigeria.
[3]Department of Anatomy University of Jos, Jos, Plateau State, Nigeria.
E-mail: conceptmaster1@yahoo.com

Abstract: This paper discusses the reaction at the inter-vertebral disc. The weight distribution on the vertebrae indicates that the L_5 bears the greatest weight and hence the reaction at the inter-vertebral disc between L_5 and S_1 is greatest. This suggests that the inter-vertebral disc between L_5 and S_1 is more prone to injury than other discs. Also, result shows increase in reaction in backward bending and decrease in reaction in forward bending. This explains that backward bending can easily result in a lower back pain than forward bending.

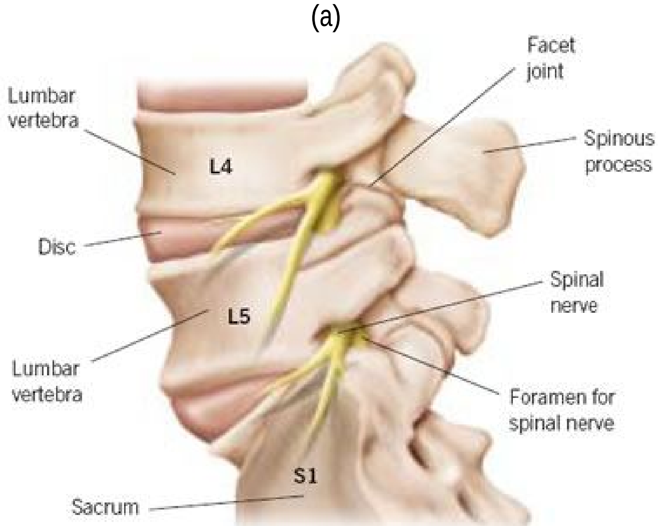
Keywords: Lumbar, Vertebrae, Reaction, Weight, Disc.

INTRODUCTION

The lumbar vertebrae are the largest of the vertebrae because of their weight-bearing function supporting the torso and head[1]. The L_5 vertebra (or the lumbar vertebra 5) is the last of the five lumbar vertebrae, positioned at the bottom of the lumbar curve of the back and just above the sacrum. Their articulating bodies are especially large and rather kidney-shaped with slightly concave faces above and below, plus a more deeply concave curve in the back. The L_5 additionally lacks costal facets. Located in the lumbar (from the Latin word for 'loins') or pelvic region, the lumbar vertebrae provide substantial support to the rest of the spinal column rising above it. In particular, the fifth lumbar vertebra is distinct from the $L_{1\text{-}4}$ vertebrae in being much larger on its front side than in the back. Its spinous process, on the other hand, is smaller than in the other lumbar vertebrae with a wide, four-sided shape that comes to a rough edge and a thick notch. The L_5 vertebra's transverse process is particularly thick, and a wider space separates the inferior articular processes. However, like the other lumbar vertebrae, the L_5 lumbar vertebra has strong pedicles, broad laminae, and long, thin transverse processes. The laminae are wider than they are tall, and the resulting vertebral arch encloses a triangular vertebral foramen somewhat smaller than that found in the cervical vertebrae but larger than the thoracic. Significant among its seven processes are three tubercles, among them the superior mammillary process and in the inferior position the accessory process[2].



(a)



(b)

Figure 1.1: Structure of Lumbar Spine Showing the Vertebrae and the Inter-Vertebral Disc[3]

Low Back Pain or Lumbago: Is a common musculoskeletal disorder affecting 40% of people worldwide at some point in their lives. Low back pain (often abbreviated as LBP) may be classified by duration as acute (generally pain lasting less than six weeks), sub-chronic (six to 12 weeks), or chronic (more than 12 weeks). The condition may be further classified by the underlying cause as mechanical, non-mechanical, or referred pain. For most episodes of low back pain, a specific underlying cause is never identified or even sought, and the pain is attributed generally to mechanical problems such as muscle strain or joint sprain[4]. The risk of experiencing low-back pain from disc disease or spinal degeneration increases with age. Over time, the inter-vertebral discs lose flexibility and shock-absorbing capability. This decreased ability to handle shock increases stresses on the spine components, which causes the ligaments to thicken and growth to occur on the bony surfaces of the vertebrae. As a result, there is less space through which the spinal cord and nerve roots may pass. This process is the suspected cause of the increased susceptibility of middle-aged adults to nonspecific low back pain[5]. Physical causes may include osteoarthritis, rheumatoid arthritis, degeneration of the discs between the vertebrae or a spinal disc herniation, a vertebral fracture (such as from osteoporosis), or rarely, an infection or tumor[6]. However, most of the time, the exact cause of the pain cannot be found. Low-back pain is also the most common cause of job-related disability and a leading contributor to missed work[7,8,9]. Acute or short-term back pain generally lasts from a few days to a few weeks. Most acute back pain is mechanical in nature –the result of trauma to the lower back or arthritis. Pain from trauma may be caused by a sports injury, work around the house or in the garden, or a sudden jolt such as a car accident or other stress on spinal bones and tissues. Symptoms may range from muscle ache to shooting or stabbing pain, limited flexibility and/or range of motion, or an inability to stand straight. Occasionally, pain felt in one part of the body may "radiate" from a disorder or injury elsewhere in the body[10].

Methodology

Mafuyai *et al.,* (2013) showed that the coordinate of center of mass of a lumbar spine is given by

$$Y_c = \frac{\dfrac{\sin\frac{\pi\mu}{l}(Y \pm |\beta|)}{\left(\frac{\pi\mu}{l}\right)} - Y\cos\frac{\pi\mu}{l}(Y \pm |\beta|)}{\cos(\pm|\beta|) - \cos\frac{\pi\mu}{l}(X \pm |\beta|)}$$

$$X_c = \frac{\frac{1}{2}\left(\frac{l}{\pi} \mp |\alpha|\right)\left(\dfrac{\left(\frac{\pi\mu}{l}\right)}{\left(\frac{\pi\mu}{l}\right)+1}\right)\left(Y - \sin\frac{\pi\mu}{l}(Y \pm |\beta|).\cos\frac{\pi\mu}{l}(Y \pm |\beta|)\right)}{\cos(\pm|\beta|) - \cos\frac{\pi\mu}{l}(Y \pm |\beta|)} \quad (2.1)$$

calculation using equation (2.1) [11] shows that the center of mass of a lumbar spine is not located on the spine itself [12]

Weight Distribution

Now let's consider the effect of location of center of mass to weight distribution at the vertebrae

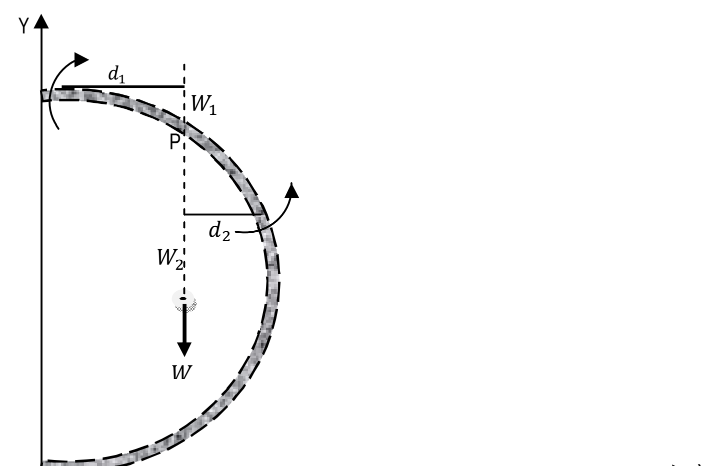


Figure 2.2.1: Moment Direction at Alternating Vertebra Due to Effect of Weight at the Center of Mass

In figure 2.2.1, the vertebrae on the left of line of action of the weight will experience a clockwise moment while those on the right hand side will experience anticlockwise moment for an effect of W at point P. Table 3.1 and column 5 and 7[13] implies that d_1 is always greater than d_2 and if $W_1 = W_2 = W$ then there will be a resultant clockwise turning effect at point P if it were movable or some deformation of shape such as an elongated s may result if P is fixed. Since none of these is the case, then the equilibrium condition implies that clockwise turning moment must be equal to anticlockwise turning moment [14]. Therefore,

$$W_1 d_1 = W_2 d_2 \qquad (2.2)$$

And,

$$W_2 = \left(\frac{d_1}{d_2}\right) W_1 \qquad (2.3)$$

But,

$$W_1 = W + W_2 \qquad (2.4)$$

Substituting equation (2.4) in (2.3) and simplifying we have

$$W_2 = \frac{\left(\frac{d_1}{d_2}\right) W}{\left(1 + \frac{d_1}{d_2}\right)} \qquad (2.5)$$

Since $d_1 > d_2$ then $W_2 > W_1$ this means that the vertebra on the right hand side of the line of action of the concentrated weight W of the body will bear the greatest burden of the weight. This means that reaction[15] at the inter-vertebral discs on the right hand side of the line of action of the concentrated weight is greater

Variation of Weight and Reaction with Posture Change

Since the weight distribution is a function of moment arm as seen in equation (2.5) then using equation (2.1) with the help of equation (2.19) [11], Table 2.3.1 and 2.3.2 have been calculated for a lumbar spine with arc length $l = 20cm$ and chord length $Y = 10cm$ at various action parameter β.

Table 2.3.1: Ratio of Moment Arms for Alternating Vertebra, and that of Other Posture to Neutral Posture at Various Action Parameters for Backward Bending

0.0000	3.80460	2.56077	1.48572	1.00000
0.0044	3.80723	2.56254	1.48573	1.00069
0.0087	3.80993	2.56414	1.48585	1.00132
0.0131	3.81281	2.56566	1.48609	1.00191
0.0175	3.81572	2.56715	1.48636	1.00249
0.0218	3.81862	2.56855	1.48668	1.00304
0.0262	3.82161	2.56996	1.48703	1.00359
0.0305	3.82451	2.57136	1.48735	1.00414
0.0349	3.82759	2.57268	1.48778	1.00465
0.0393	3.83070	2.57397	1.48825	1.00515
0.0436	3.83381	2.57516	1.48877	1.00562
0.0480	3.83709	2.57628	1.48939	1.00606
0.0524	3.84016	2.57761	1.48981	1.00658
0.0567	3.84339	2.57868	1.49045	1.00699
0.0611	3.84663	2.57984	1.49103	1.00745
0.0655	3.85007	2.58080	1.49181	1.00782
0.0698	3.85342	2.58175	1.49256	1.00819
0.0742	3.85687	2.58270	1.49335	1.00856
0.0786	3.86028	2.58369	1.49410	1.00895
0.0829	3.86375	2.58452	1.49496	1.00927
0.0873	3.86732	2.58535	1.49586	1.00960

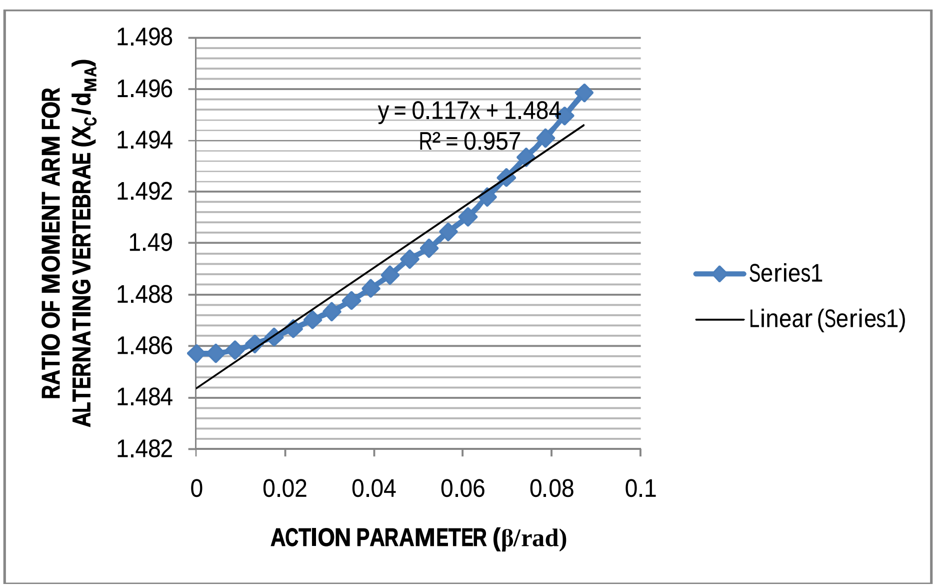


Figure 2.3.1: Graph of Ratio of Moment Arm for Alternating Vertebrae Against Action Parameter for a Backward Bending

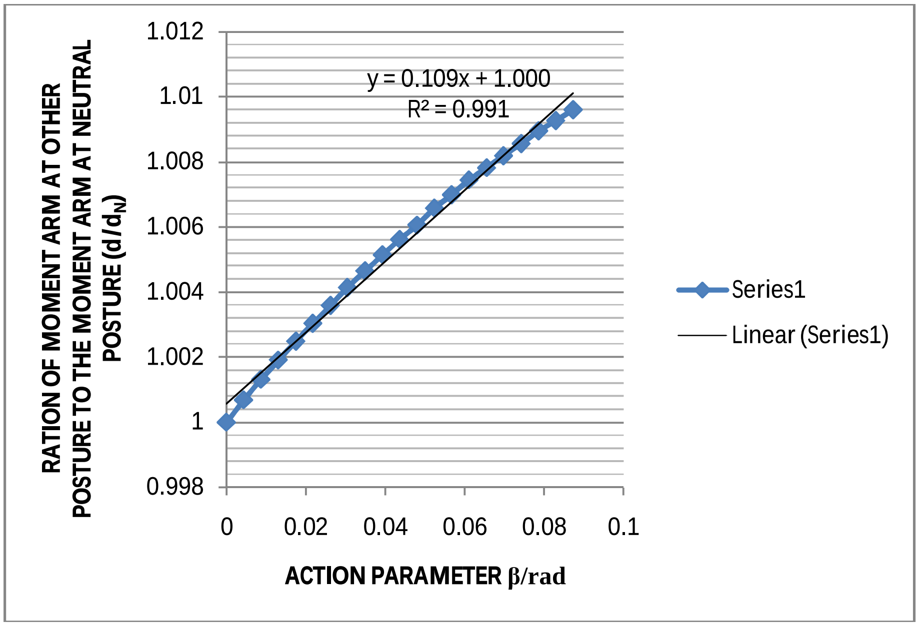


Figure 2.3.2: Graph of Ratio of Moment Arm at Other Posture to the Moment Arm at Neutral Posture Against Action Parameter for a Backward Bending

Table 2.3.2: Ratio of Moment Arms for Alternating Vertebra, and that of Other Posture to Neutral Posture at Various Action Parameters for Forward Bending

$\lvert\beta\rvert/rad$	$X_c(cm)$	$d_{MA}(cm)$	X_c/d_{MA}	d/d_N
0.0000	3.8046	2.5608	1.4857	1.0000
0.0087	3.7991	2.5576	1.4854	0.9987
0.0175	3.7938	2.5541	1.4854	0.9974
0.0262	3.7888	2.5503	1.4856	0.9959
0.0349	3.7838	2.5467	1.4858	0.9945
0.0436	3.7791	2.5427	1.4863	0.9930
0.0524	3.7746	2.5384	1.4870	0.9913
0.0611	3.7702	2.5341	1.4878	0.9896
0.0698	3.7658	2.5298	1.4886	0.9878
0.0786	3.7617	2.5251	1.4897	0.9861
0.0873	3.7578	2.5208	1.4907	0.9844

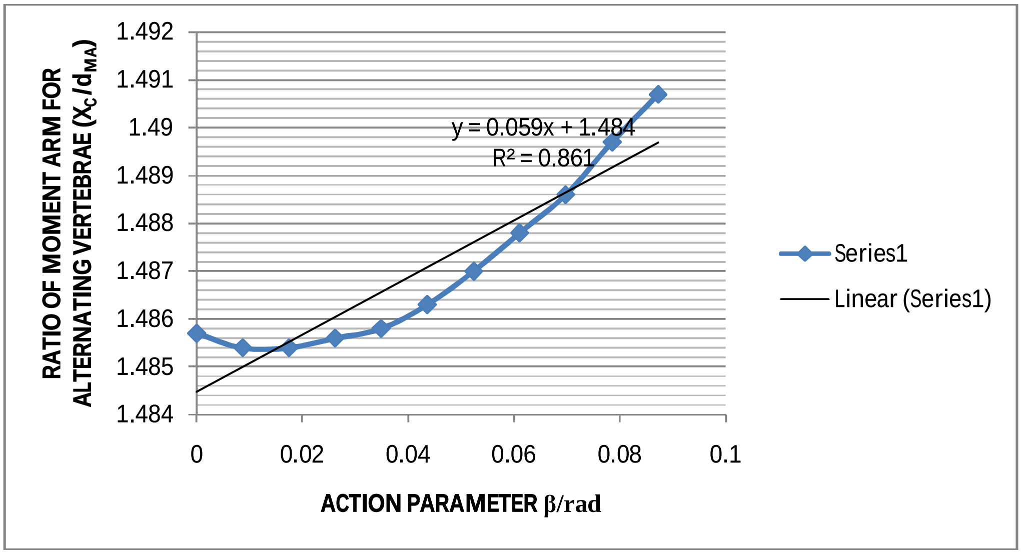


Figure 2.3.3: Graph of Ratio of Moment Arm for Alternating Vertebrae Against Action Parameter for a Forward Bending

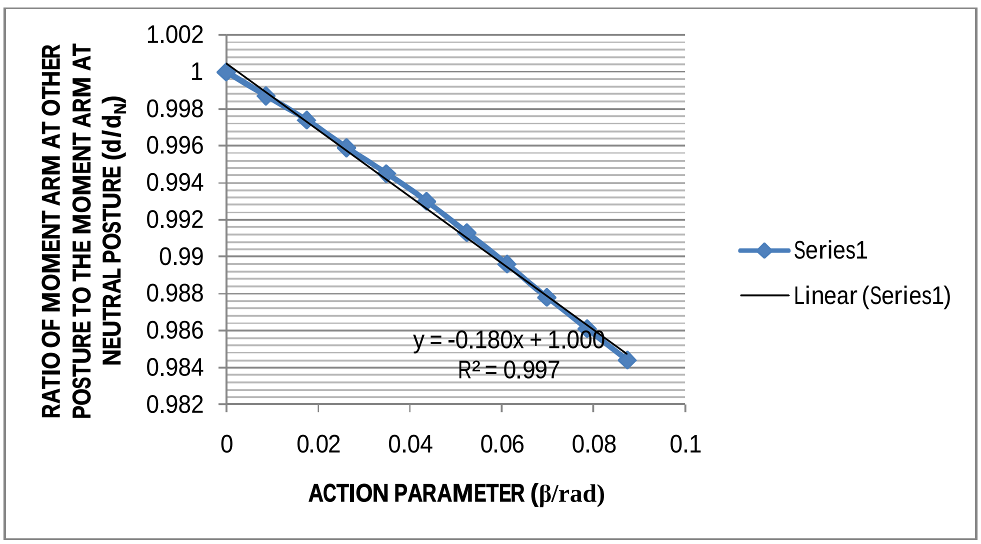


Figure 2.3.4: Graph of Ratio of Moment Arm at Other Posture to the Moment Arm at Neutral Posture Against Action Parameter for a Forward Bending

RESULTS AND DISCUSSION

Equation (2.3) relates the weight borne by alternating vertebrae with the line of action of the center of mass as the reference line (Figure 2.2.1). The relationship is dependent on the ratio of the moment arm of the alternating vertebrae and in backward bending this ratio is greater than unity as seen from column 4 of Table 2.3.1. This means , that is the vertebra on the right hand side of the line of action of the concentrated weight of the body will bear the greatest burden of the weight. This means that reaction[15] at the inter-vertebral discs on the right hand side of the line of action of the concentrated weight is greater.

In Figure 2.3.1, the graph has a positive slope which shows an increase in the weight W_2 as the lumbar spine bends backward and hence the reaction at the inter-vertebral disc. The slope of Figure 2.3.2 is also positive which indicates an increase in moment arm with backward change in posture of the lumbar spine. This means that the reaction at the inter-vertebral disc increases also, however the slope (0.109) is less than the slope (0.117) of the Figure 2.3.1 which means that the weight W_2 will always increase in much more proportion to the reaction during backward bending. This will therefore leads to increase stress on the inter-vertebral disc and other nerve tissues (Figure 1.1b) which causes pain at the lower back[10,5].

In forward bending, the weight W_2 increases but slowly compare to backward bending as seen from the slope (0.059) of Figure 2.3.3 which is smaller than of Figure 2.3.1. However, the slope of Figure 2.3.4 shows a rapid decrease in moment arm with changing posture in forward bending. The negative sign simply means the reaction is from the opposite side of the inter-vertebral disc (Figure 1.1a). The slope (0.180) of Figure 2.3.4 is greater than that of Figure 2.3.3 which means that the reaction increases in much more proportion to the weight and this may be due to the thickening nature of the disc from this side (Figure 1.1a). This great increase in cushioning effect of the disc can be seen as decrease in reaction during forward bending.

X_c is the moment arm of the vertebra Th_{12} and d_{MA} is the moment arm of L_5 [13]. Since the ratio X_c/d_{MA} is greater than unity as seen in column 4 of Table 2.2.1 and 2.2.2; despite that X_c is less than the moment arm of the exact alternating vertebra of L_5, then L_5 must be the lumbar vertebra bearing the greatest weight. This suggest the reason for it structure and properties differing from the other vertebrae [2].

CONCLUSION

Equation (2.3) defines weight distribution among the vertebrae and equation (2.5) relates the distributed weight to the concentrated weight. Figure 2.3.1 and 2.3.2 indicate an increase in the weight and reaction during backward bending and this suggest that backward bending can cause more lower back pain. However, the reverse is the case with forward bending.

Also, the result of this work can help in medical diagnoses of lower back pain as it point out areas susceptible to injuries such as the thin side of the inter-vertebral disc and the nerves, tissues and the inter-vertebral disc between L_5 and S_1. This is because the source of injury may not easily associated with where the pain seem to be coming from [10].

REFERENCES

1. Lumbar-Spine-Lower-Back-Structure-Function;http://healthpages.org/anatomy-function/lumbar-spine-lower-back-structure-function. Accessed July 24, 2013.

2. L_1-5th Lumbar-Vertebra; http://www.innerbody.com/anatomy/skeletal/l5-5th-lumbar-vertebra Accessed July 24, 2013.

3. Images of Lumbar Spine; Retrieved from https://www.google.com.ng/search?q=structure+of+lumbar+spine&client=firefox-a&hs=ytI&rls=org.mozilla:enUS:official&channel=np&tbm=isch&tbo=u&source=univ&sa=X&ei=J2ZxUuH3Du7s0gWh14H4CQ&ved=0CEQQsAQ&biw=2000&bih=995#facrc=_&imgdii=_&imgrc=1vmfAgeyL9hgkM%3A%3B6gX0BhgUjKaLsM%3Bhttp%253A

%252F%252Fwww.eorthopod.com%252Fsites%252Fdefault%252Ffiles%252Fimages%252Flumbar_anterior_fusion_anatomy01.jpg%3Bhttp%253A%252F%252Fwww.eorthopod.com%252Fcontent%252Fanterior-lumbar-interbody-fusion%3B400%3B400. Accessed October 30, 2013.

4. Lower Back Pain; https://en.wikipedia.org/wiki/Low_back_pain Accessed July 28, 2013.

5. Borczuk, Pierre (July 2013). "An Evidence-Based Approach to the Evaluation and Treatment of Low Back Pin in the Emergency Department". *Emergency Medicine Practice* **15** (7). Retrieved from https://en.wikipedia.org/wiki/Low_back_pain Accessed July 28, 2013.

6. "Fast Facts About Back Pain". *National Institute of Arthritis and Musculoskeletal and Skin Diseases*. National Institute of Health. September 2009. Retrieved from https://en.wikipedia.org/wiki/Low_back_pain Accessed July 28, 2013.

7. Bigos S, Bowyer O, Braen G, *et al.,* Acute Low Back Problems in Adults. Clinical Practice Guideline No.14. AHCPR Publication No. 95-0642. Rockville, MD: Agency for Health Care Policy and Research, Public Health Service, U.S. Department of Health and Human Services, December, 1994.

8. Hoy DG, Bain C, Williams G, March L, Brooks P, Blyth F, Woolf A, Vos T, Buchbinder R. “A Systematic Review of the Global Prevalence of Low Back Pain.” Arthritis Rheum. 2012 Jan 9. Accessed from; http://www.ncbi.nlm.nih.gov/pubmed/22231424

9. Medline Plus. Low-Back Pain-Chronic. http://www.nlm.nih.gov/medlineplus/ency/article/007422.htm. Accessed July 25, 2013.

10. National Institute of Neurological Disorders and Stroke. Low-Back Pain Fact Sheet. http://www.ninds.nih.gov/disorders/backpain/detail_backpain.htm. Accessed July 25, 2013.

11. Mafuyai M. Y., Babangida G. B. *et al.,* (2013). Variation of the Center of Mass with Changing Posture of the Lumbar Spine, *Nigeria Journal of Mathematical Physics.* Submitted.

12. Center of Mass; https://en.wikipedia.org/wiki/Center_of_mass Accessed July 28, 2013.

13. Mafuyai M.Y. (2013), Physical Model of the Lumbar Spine and the Anatomical Consequences of the Displacement of Centre of Mass, M.Sc. Thesis Submitted to Physics Department University of Jos. Unpublished.

14. Emeka E. I (2005), Essential Principle of Physics, First Edition, *Published in Jos by Enic Education Series.*

15. http://www.eng.auburn.edu/~marghitu/MECH2110/C_3.pdf Accessed August 22, 2013.

Reference to this paper should be made follows: M.Y. Mafuyai *et al.,* Reaction at the Inter-Vertebral Disc Due to Variation of Posture of Lumbar Spine and the Consequences on the Lower Back Pain. *J. of Sciences and Multidisciplinary Research,* Vol. 5, No. 2, Pp. 159 – 168.