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FINITE ELEMENT ANALYSIS OF AN INDIVIDUAL WITH SEVERE KYPHOSCOLIOSIS

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Abstract. The human spine is a complex structure that can present deformities like kyphoscoliosis (KS). The patients with KS often present chronic back pain (50% to 61%). The aim of this paper investigates if the seated position creates areas with concentrated stress in the upper body, contributing to their chronic back pain. In order to achieve this, a finite element analysis (FEA) was done of an individual with KS while seated in two conditions: first with a concentrated force provided by the backrest, then with a more distributed one. The analysis was made with the mechanical properties of the Skeletal Muscle. The images generated as a result of FEA shows that the superior part of the spine as well as the sacral part have low values of stress. The lower back region, on the other hand, presents itself as a stress raiser which may cause back pain. It was also observed that the less concentrated force generated a result with lower values for the stresses within the object, which sugests that a distributed force could collaborate for the decrease of the back pain.

Keywords: kyphoscoliosis, finite element analysis, biomechanics

1. INTRODUCTION

According to Kurutz, (2010), the human spine is a complex structure that belongs to the axial skeleton along with the rib cage and the braincase. One of its principal biomechanical functions is to provide the load transference within itself. The spine can present deformities like kyphoscoliosis (KS) (Brodbeck and Crippa, 1977) According to McMaster et al., (2007) KS is an excessive curvature of the spinal column in the sagittal and coronal plane. Bergofsky (1979) affirms that KS is the most common spinal deformity and this disease affects 4% of the population worldwide. The research of Conti et al., (1997) informs that patients with KS present a short stature and the presence of a hump created by the deformed thoracic cavity, as can be seen in the study by Bergofsky et al. (1959) in Fig 1.
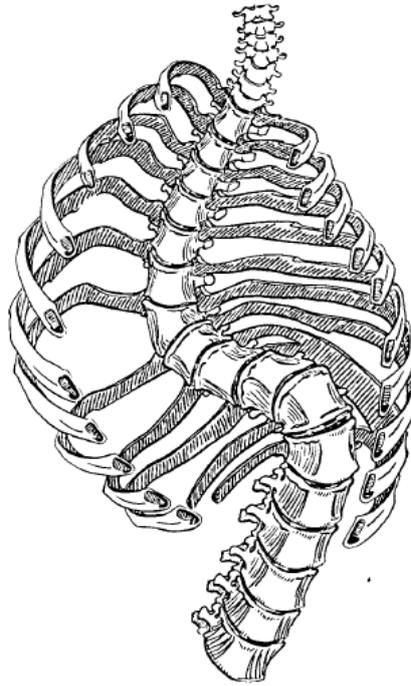
Figure 1 Schematic representation of a spine with kyphoscoliosis
Available from: https://journals.lww.com/md-
journal/Citation/1959/09000/Cardiorespiratory_Failure_in_Kyphoscoliosis.4.aspx#pdf-link

According Pajdziński et al. (2017) KS is a important complex, multidisciplinary clinical problem. Deyo et al. (2006) affirm that patients with KS often present chronic back pain (50% to 61%). Al-Qadi (2018) says that prolonged standing worsens symptoms, which negatively impacts activities of daily living. As the prolonged orthostatism worsen the pain symptoms, it can be implied that these individuals spend a considerable part of their days seated. Marques et al. (2010) claim there isn't an ideal posture for sitting, although some are more recommended because they reduce the stress of some muscles, like those in the lower back region. Eventhough there are many types of chairs, it isn't known whether these furniture is suitable for people with KS, since their spine has some deformation. The aim of this paper is to investigate if the seated position creates areas with concentrated stress in the upper body, contributing to their chronic back pain. In order to achieve this, a finite element analysis (FEA) will be done of an individual with KS while seated.

2. MATERIALS AND METHODS

The biomechanical behavior of the human upper body involves not only the spine, but also the muscles and tendons. As the spine of individuals with KS have a complex vertebral deviation, it would be necessary a magnetic resonance to model it precisely. As this data is nonexistent, it was chosen to, at first, utilize the external shape of the body and to do the FEA with the mechanical properties of the Skeletal Muscle. The EinScan-Pro+ (SHINING 3D Tech, Co) was used for the scanning of a female individual with a severe KS.The software Meshmixer version 3.5 (Autodesk, Inc.) was used for the union of the scanned body parts, creating a shell with the approximate characteristics of the whole body (Fig. 2). As the objective is to analyze the behavior of the muscles that touch the backrest and the seat, a region of the scanned body was removed (the selected region matches the portion that is supported on a chair) for the simulation, the elements were remeshed for better extrusion of the surface. Then the surface was extruded 25 mm and the model was simplified for the simulation (Fig 3). This extruded model was used as a base to generate a solid in the Ansys version 19.0 (Ansys, Inc.) software, which was also used for the Static Structural FEA. The analysis is a simplified version considering only the hyperelastic behavior of the Skeletal Muscle in the region.

Figure 2 The whole human body's model

Figure 3 The portion selected to analysis

2.1 Material

The material behavior is considered as hyperelastic for FEA of skeletal muscle tissue. Herzog, (2000) presents the Mooney Rivlin 9 parameter model (Tab. 1) which is used for specifying the hyperelasticity of skeletal muscle tissue and the density considered as 1000 kg/m³.

Table 1. Typical input parameters for passive muscle tissue

Mooney Rivlin constant [MPa]	a10	a01	a20	a11	a02	a30	a21	a12	a03
	10	0	10	0	0	6,6667	0	0	0

2.2 Analysis Settings

The face corresponding to the ischial tuberosity was supported by a fixed support, preventing both its displacement and rotational movement. According to Resende (2006), 4,20% of the human body's weight is upheld by the backrest of the chair. Since this force is normal to the backrest surface, which had an angulation of 105° with the seat, in the analysis was added a force with the components for the Z axis and X axis according to the Eq. (1) and Eq. (2).

$$F_z = 0,042gM \tag{1}$$

$$F_x = \frac{F_z}{tan(105-90°)} \tag{2}$$

Where F_z is the component of the force in the longitudinal axis, F_x is the component of the force in the anther-posterior axis, g is the acceleration of the gravity defined by the ANSYS software and M is the estimated mass complete body. The value used for these variables are described in the Tab. 2.

Table 2. Values of the variables used on ANSYS

Variable	Value
g	9.8066 m s^{-2}
M	60 kg
F_z	24.71 N
F_x	92.22 N

The acceleration of the gravity was included in the analysis in the longitudinal axis. The volume of the solid was calculated by the software and using the density already mentioned it is possible to determine the total gravity force affecting the object. The volume and the resulting force are described in the Tab 3.

Table 3. Values of the volume of the solid and the gravitational force, both calculated by the ANSYS software.

Variable	Value
Volume	0,006046 m³
Total gravitational force	59.2907 N

It is known that KS causes spine deformities, so the posture of a seated person with this condition might not be ideal. Acknowledging this, two FEA were made with two different distributions of the backrest force. The Figure 4.a illustrates the first one, with a more concentrated force applied to the most prominent region of the deformity. The Figure 4.b, on the other hand, exemplifies the second one, with a more evenly distributed force.
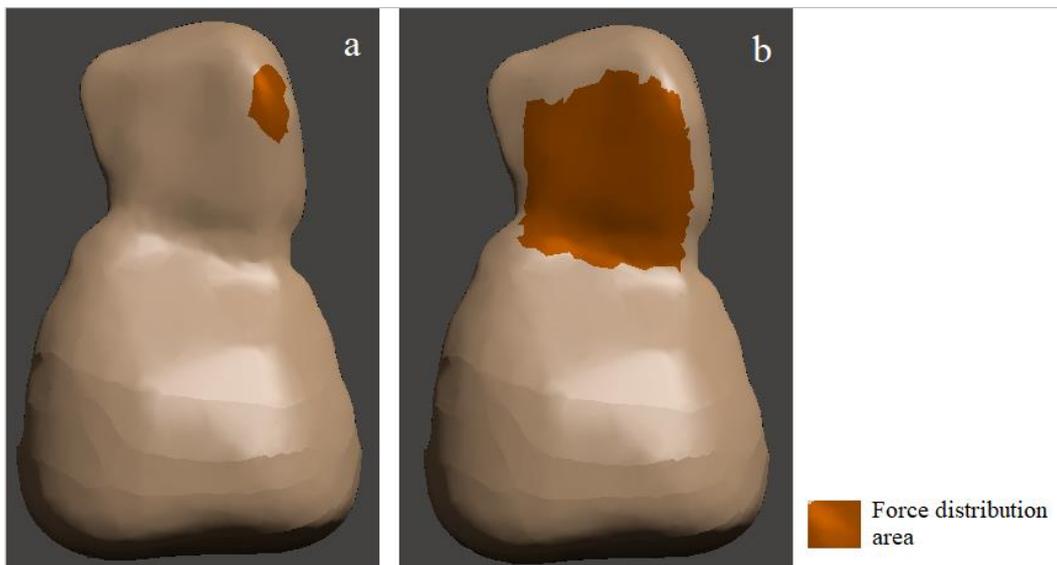

Figure 4.a and 4.b Distribution of force in the thorax in smaller (a) and larger area (b)

After determining the boundary conditions, the software executed the analysis to generate the desired results of distribution of stresses. It was considered that the most relevant analyses were the shear stress in the anteroposterior plane, the maximum shear stress and the Von Mises stress. The images which represent the solution of the analysis were taken in the Statical Structural tool and in the Result tool of the software, according to the ANSYS limitations.

3. RESULTS

After determining the boundary conditions and the force applied in both proposed distributions, the results obtained are shown in the Figs. 5, 6, 7, 8, 9 and 10. It could be perceived that the general aspect of the distribution of stresses were

similar for both conditions, but with variations for the values. The results also show that the lumbar spine is the region with the highest values of stress, which could indicate a reason for the chronic pain, common in this part of the body.

The Figures 5 and 6 were obtained using the Results tool. They present the shear stress in the anteroposterior plane for the concentrated condition, Fig. 5 and for the distributed condition, Fig. 6. Their comparison shows that the lower back, whilst in the distributed condition, has a much lower value of stress, approximating $5,6 \times 10^2$Pa. Nonetheless, the punctual distribution changes that value to $-3,1 \times 10^5$Pa. The signal in the shear stress analysis can be ignored, so this difference characterizes a great increase of stress. It can also be observed that left and right extremes of the lower back contain the highest absolute values in both conditions, which also reduced in the more evenly distributed. This reduction could contribute to the diminishing of the chronic pain.
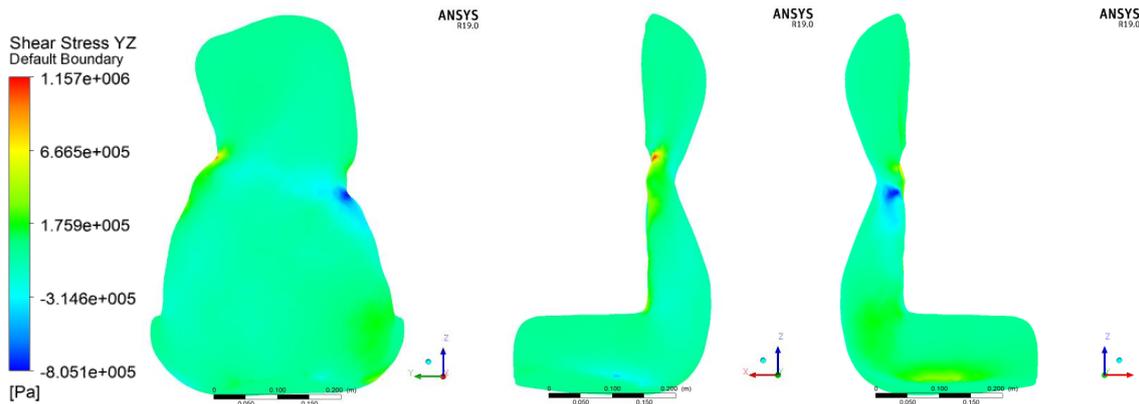

Figure 5 Shear Stress YZ concentrated condition - posterior, left lateral and lateral views
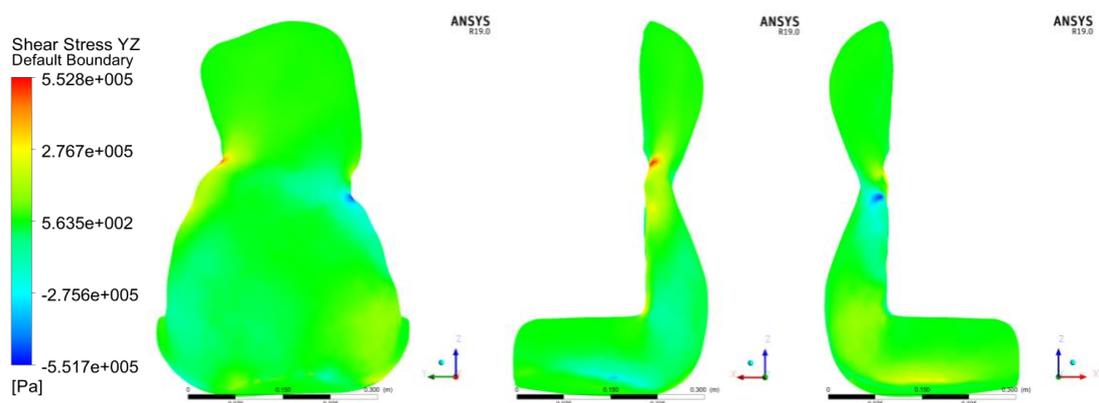

Figure 6 Shear Stress YZ distributed condition - posterior, left lateral and lateral views

The Figures 7 and 8 were obtained in the Static Structural tool, since the Results tool couldn't provide the maximum shear stress analysis. The Figure 7 presents the concentrated condition, whilst the Fig. 8 presents the distributed condition. The distribution of stresses in both figures is almost equal, but when the graphic subtitles is taken into analysis, it becomes possible to perceive that the values are higher in the concentrated condition. The stresses reduce from $5,7 \times 10^5$Pa to $2,7 \times 10^5$Pa in the lower back, which represents more than a factor of 2. The difference isn't as discrepant in the shear stress in the anteroposterior plane, but it's also very relevant. The point of maximum stress can be ignored, because, since it is in the edge of the solid, the probable reason for this high value is the discontinuity of the object, in which case it wouldn't represent the real situation.
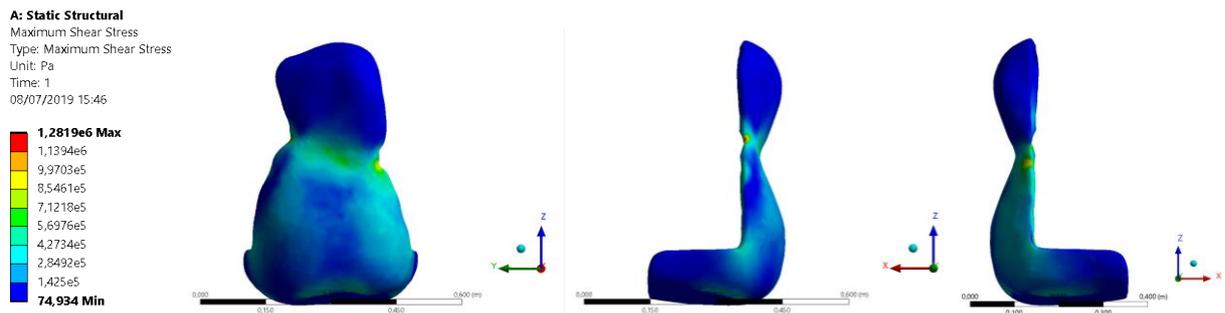
Figure 7 Maximum Shear Stress concentrated condition - posterior, left lateral and lateral views
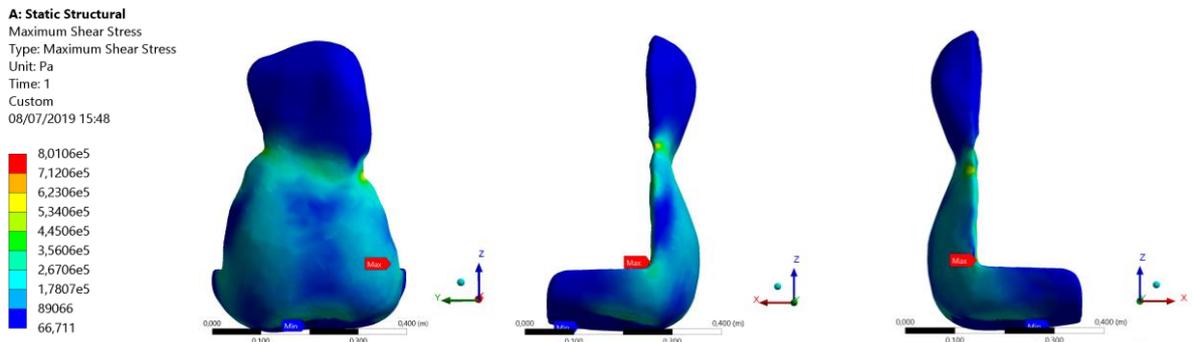

Figure 8 Maximum Shear Stress distributed condition - posterior, left lateral and lateral views

The Figures 9 and 10 were obtained using the Results tool, and they present the Von Mises stress. The Figure 9 reveals the concentrated condition, whilst the Fig. 10 shows the distributed one. Just like the Fig. 7 and 8, these two have distributions of stress which are very similar, but their values distinguish when the subtitles are taken into analysis. The subtitle couldn't be detailed enough to give a precise description of more points in the region, as this would make the image too polluted with information and hard to comprehend. Nevertheless, the given information provides the possibility to make a rough estimation of the Von Mises stresses by a factor of 2. It's possible to notice also that the Von Mises stress is higher than the maximum shear stress, for both the concentrated and the distributed condition.
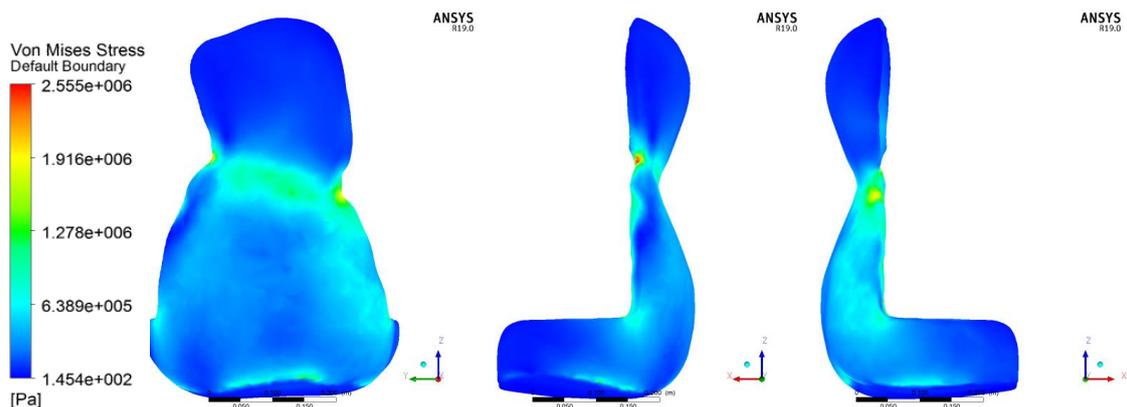

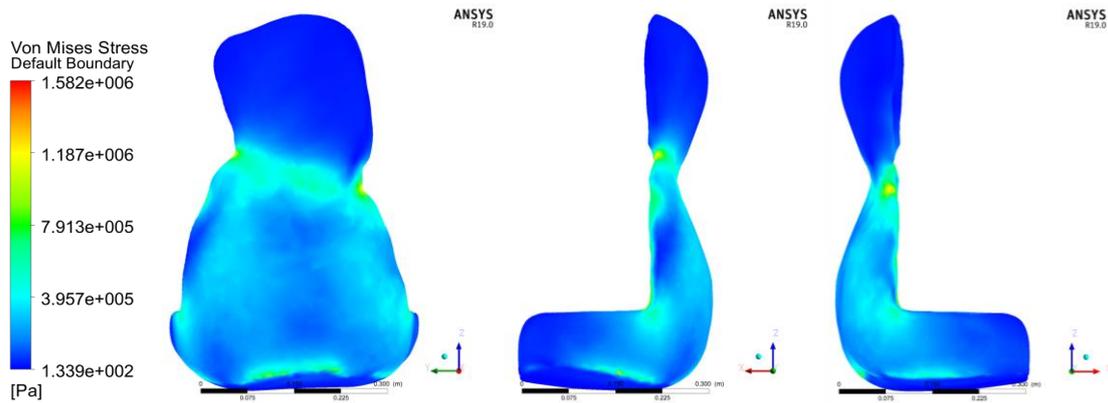Figure 9 Von Mises Stress concentrated condition - posterior, left lateral and lateral views

Figure 10 Von Mises Stress distributed condition - posterior, left lateral and lateral views

It can be noticed that in the region below the Ribcage it is formed a strip which is inclined to the hip support (Fig. 11). This strip has the higher values of stress for all the analysis made, in both conditions. It can collaborate for the chronic back pain because, when analyzing the simulated body divided by the sagittal plane, there isn't symmetry in the stress distribution, and the body tends to adjust for symmetry.
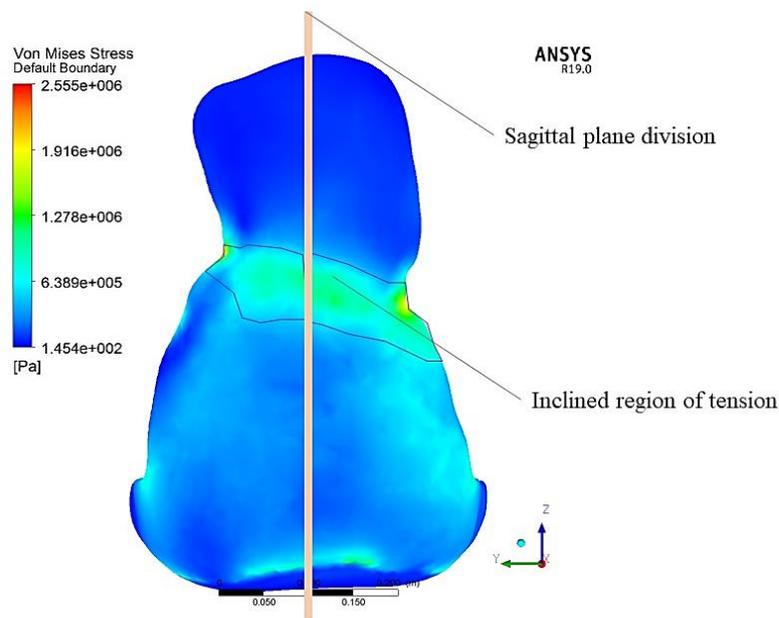

Figure 11 Von Mises Stress concentrated condition inclined region of tension

4. CONCLUSION

Having an overview at the stresses, it is possible to perceive that both the sacral and the superior region of the spine have low values of all the stresses measured. The lumbar spine under the deformity, on the other hand, presents itself as a stress raiser. Even though the values are higher in both FEAs, it's also possible to notice that the more evenly distributed load highly reduce the stress within the area. Therefore, it can be implied that seats which provide a bigger area for the load distribution could contribute for the reduction of the chronic back pain, once it would reduce the stresses.

This study was important to the initial understanding of the behavior of a seated patient with KS and his relation to the possible causes of the back pain. Giving attention to this public is essential, once it would enable a batter comprehension of the pathology and forms to improve the life condition of these people. The Mechanical Engineering and bioengineering are great contributors in this understanding. FEA simulations enable a more precise data analysis. Nevertheless, more measures must be done with humans to validate this simulation.

5. ACKNOWLEDGEMENTS

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