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# COMPUTATIONAL MODELING AND NUMERICAL SIMULATION OF NEW WHEELCHAIR SEAT-BACK SYSTEMS TO IMPROVE COMFORT AND POSTURAL ADEQUACY FOR CHILDREN WITH MOTOR DISABILITIES

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**Abstract.** Physical or motor disability may be considered a body structure or function disorder that interferes with the movement and locomotion of the individual, and this may impact several activities such as school and work. The current work focused on the development of assistive technology and postural adequacy areas, aiming the social inclusion of children with motor disabilities in the educational system in the Pernambuco state. In this work, a computational model was developed to represent the current seat-back system used by children. In order to simulate representative loading conditions, it was used temperature digital data collected in the seat-back system through the thermography technique. Those data have been transformed into pressure maps and implemented as mechanical loads in the computational model. Numerical simulations were then performed using the commercial software COMSOL Multiphysics®. The results of the simulations were analyzed to identify critical stress concentration zones and high contact pressure in the actual seat-back system, which can possibly lead to bedsores and discomfort. The next step of the work was to propose new seat-back systems, improving better posture and comfort to the children. Therefore, new mathematical models were implemented in the software to test and evaluate the performance of different foams.

**Keywords:** computational modeling, numerical simulation, wheelchair seat-back.

## 1 Introduction

The 2010 census carried out by the Brazilian Institute of Geography and Statistics shows that 7.5% of children aged 0 to 14 years old had at least one type of disability. Of these, 1% have motor disabilities [1]. The clinical and functional status of children with motor disabilities, as well as those with other disabilities that cause neuromotor dysfunction resulting from other syndromes and/or cerebral palsy, represents a challenge for educators and even for the family in their daily routine.

According to the World Report on Disability [2], "children with disabilities are less likely to attend schools, thus facing limited opportunities for human capital formation and obtaining fewer employment opportunities and lower productivity during their lifetime". Presenting tools to improve quality of life for children with motor dysfunction can help their social inclusion and becomes a challenging task involving professionals from different areas. The current project proposes the development and technological application in the area of Postural Adequation Assistive Technology, aiming for the social inclusion of children with motor deficiency.

# 2 Methodology

This work proposes a methodology for wheelchair postural assessment applied to a child with motor disabilities. The study is carried out on a patient aged lower than 12 years old. The subject has a motor deformity caused by Congenital Zika Syndrome, making him a wheelchair user. A written consent form was signed by the patient parents prior to his inclusion in the study.

To achieve postural adequacy, the pressure distribution on the wheelchair back-seat system was captured over the patient's contact area using thermography as an indirect tool for pressure assessment. Then, thermographic images will be used as input for computer simulations. The commercial software COMSOL Multiphysics®, based on the Finite Element Method has been used as a tool to realize the seat-back system modeling and numerical simulation of the seat-back systems.

## 2.1 Thermal Images

Thermal Images Acquisition

Thermographic images were obtained with a FLIR T540 IR camera. To obtain more reliable temperature measurements, a standardized protocol was used for the acquisition pos thermal images and is described as follows: a) the patient must rest in his wheelchair for 10 minutes before acquiring the image for temperature acclimatization; b) after the acclimatization period, the patient is removed from his wheelchair and thermographic images of the seat-back system of the chair; c) the temperature matrices from the thermographic images are treated in Python to obtain the temperature distribution over the area of interest.

Thermal Images Pre-Processing

The infrared (IR) image pre-processing step was performed in Python. The temperature matrix was extracted from the IR images with Flir Tools software and then exported to Python. The temperature data was divided into different temperature ranges, giving rise to different levels of visualization of the patient's contact area with the seat or backrest. Then, a manual segment was performed to extract from the original image the area of interest. Figure 1 shows the thermographic image obtained from the wheelchair back system and Figure 2 shows the segmented visualization levels from the back system temperature data.

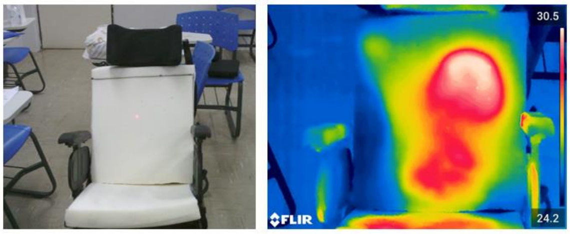


Figure 1. Thermographic image from the wheelchair backrest.

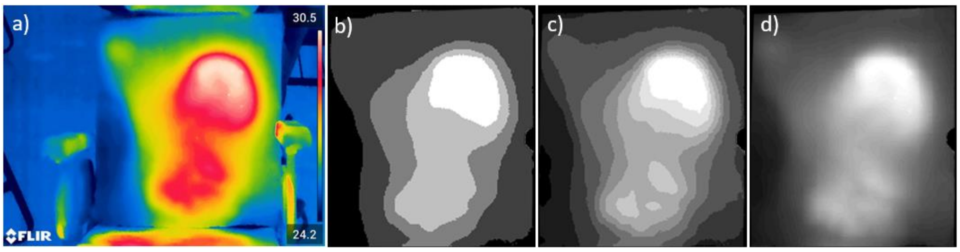

Figure 2. Segmented visualization levels from the backrest temperature data. a) Original thermographic image; b) Segmented visualization with 5 temperature intervals; c) Segmented visualization with 10 temperature intervals; d) Segmented visualization with 50 temperature intervals.

## 2.2 Simulations Methodology

The simulations for the back-seat system followed in the first instance, two approaches. For the first approach, a linear elastic material model was used, with its mechanical properties obtained through literature. In this analysis, initially, the characteristics of the current seat-back system were reproduced, and their results analyzed, and then the densities of regions of the greatest tension were modified and later analyzed again.

The second approach was through the modeling of a viscoelastic material, using the predetermined functions of the COMSOL Multiphysics® platform by Storakers [3] and Kelvin-Voight [4]. The Storakers material model is often used to model highly compressible foam, which is our case. The strain energy density function is given by:

$$Ws = \sum_{k=1}^{N} \frac{2\mu_k}{\alpha_k^2} \left(\lambda_1^{\alpha k} + \lambda_2^{\alpha k} + \lambda_3^{\alpha k} - 3 + \frac{1}{\beta_k}\left({J_{el}}^{-\alpha_k \beta_k - 1}\right)\right) \qquad (1)$$

Where $\lambda_1$ , $\lambda_2$ , and $\lambda_3$ are the principal stretches; $J_{el}$ is the elastic volume ratio; and $\mu_k$, $\alpha k$, and $\beta_k$ are the Storakers material parameters.

## 2.3 Thermal images as loads

The thermal images obtained through the methodology described before were put as a function on COMSOL Multiphysics® software and used as loads on the seat-back systems, assuming that the regions of high temperature coincided with the regions where the high pressure operated. To achieve excellence in aspects that guise the accuracy of the results, all images with different color gradients were used in the tests, Figures 3. To transform these temperature maps into pressure maps it was assumed a coefficient directly related to the child's weight, using the value of 0.6 for the back system and 0.4 for the seat system.

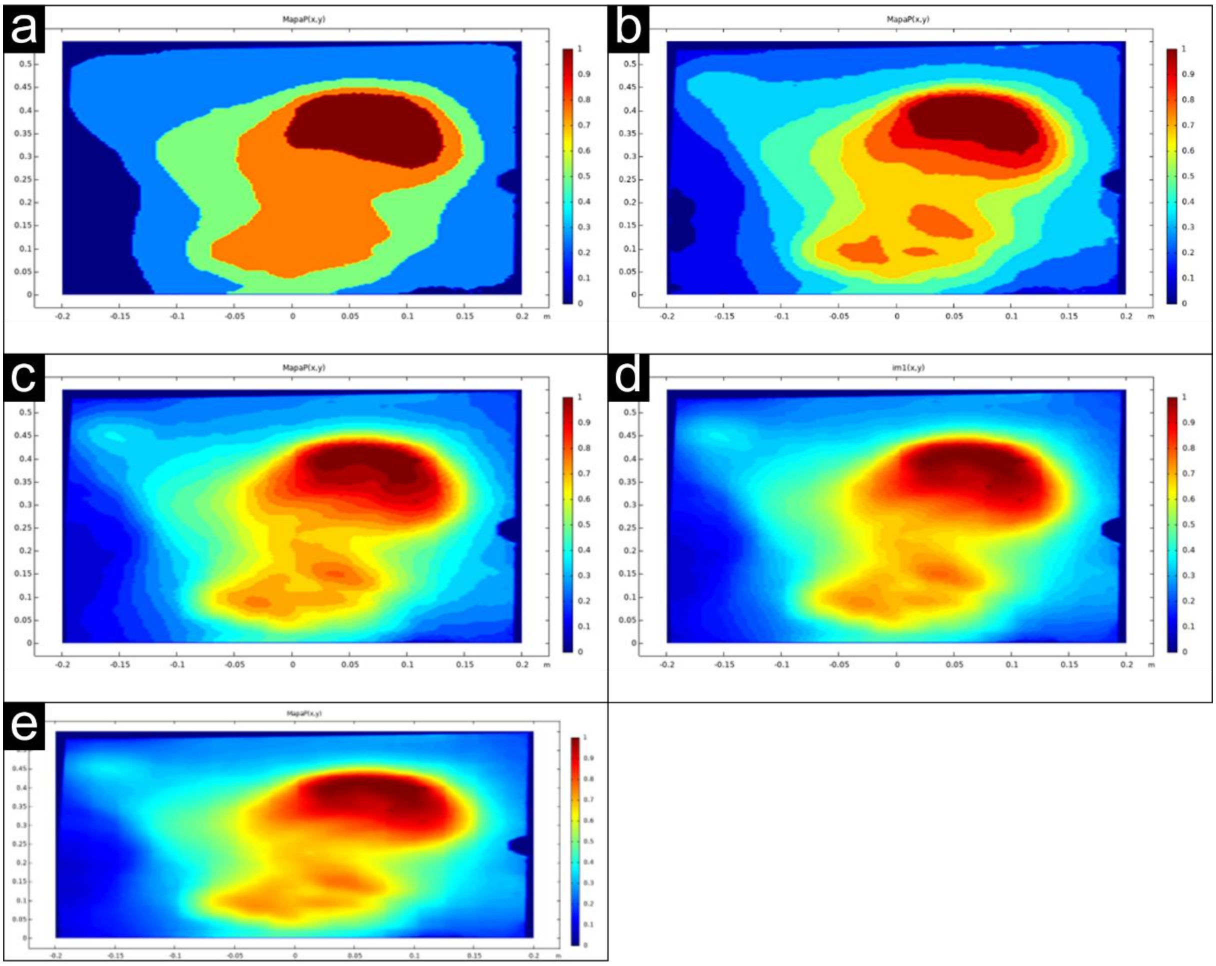


Figure 3. Backrest system pressure maps exported to COMSOL Multiphysics®. a) visualization with 5 temperature intervals; b) visualization with 10 temperature intervals; c) visualization with 25 temperature intervals; d) visualization with 50 temperature intervals; e) visualization with 100 temperature intervals.

### 2.4 Geometry modelling

After that, it was developed, on SolidWorks software, the three-dimensional geometry of the current seat-back system, Figure 4, reproducing his body dimensions and material properties , Table 1. For the seat, it was used 440 mm x 500 mm x 50 mm dimensions. For the back, it was used 440 mm x 140 mm x 550 mm dimensions.

Then, the computer-aided model was exported to the COMSOL Multiphysics® software to start the numerical simulation.

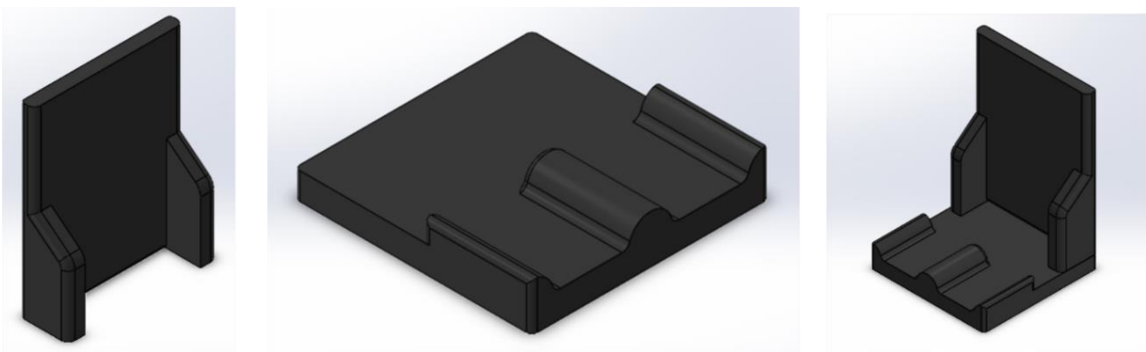

Figure 4. Pressure maps exported to COMSOL Multiphysics®

Table 1. Polyurethan mechanical properties

| Constitutive relation | Unit | Value |
|---|---|---|
| Density | Kg/m³ | 33 |
| Young's Modulus | Pa | 100e³ |
| Poison's ratio | 1 | 0.33 |
| Shear modulus | MPa | 0.82 |

### 2.5 Mesh generation

Finite element modeling of the seat-back system was performed automatically in the software using predominantly tetrahedral elements of 2nd order to suit the component curves better, presenting the best relation between elements quality and computation cost. The total number of elements was 12,556 and 10,003 for the seat and the back, respectively, figure 5.

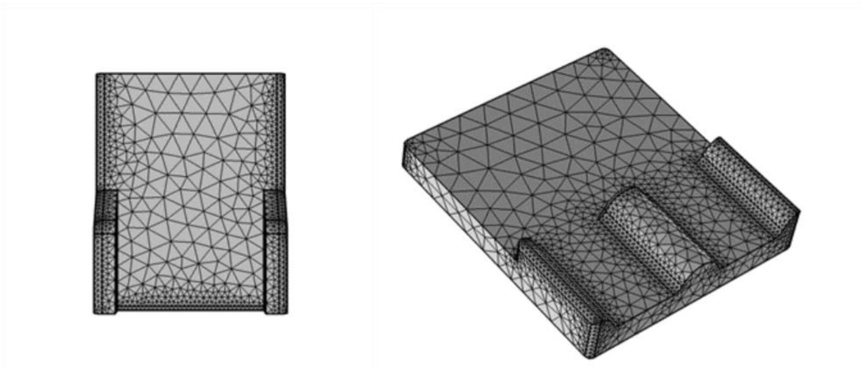

Figure 5. Seat-Back system finite element model.

### 2.6 Results

In the first instance, it is important to mention that it was observed that the variation of the gradients of the thermal images had minimal influence on the results of the analysis.

Back System

For the simulation of the linear model of equal density in all regions of the backrest, it was possible to observe that the regions of the greater tension and displacement of the component presented coherence in the results since they coincide with the regions of the greater physical deformation of the patient. As a result, a von Mises stress of 0.4 Pascal (Pa) and a total displacement of $169x10^{-6}$mm were obtained, figure 6 (a).

Then, a linear model of a foam block with a density of 23 $kg/m^3$ and the same parameters of Young's Modulus and Poison's ratio was inserted in the region of greatest stress. When running the simulation again, it was possible to observe an increase in the von Mises stress to 0.6 Pa and a decrease in the displacement to $89.55x10^{-9}$ mm, figure 6 (b).

Finally, for the same geometry of the first approach, the previously mentioned Storakers and Kelvin-Voight model were inserted maintaining, again, the parameters of Young's Modulus and Poison's ratio. At the end of the simulation, values similar to the linear model of 0.8 Pa von Mises stress and displacement of $76.44x10^{-7}$ were observed, figure 6 (c).

Seat System

For the simulation of the linear model of equal density in all regions of the seat, it was possible to observe a von Mises stress of 0.8 Pa and a total displacement of $127.37x10^{-6}$, figure 7 (a).

Then, a linear model of a foam block with a density of $23kg/m^3$ and the same parameters of Young's Modulus and Poison's ratio was inserted in the region of greatest stress. When running the simulation again, it was possible to observe an increase in the von misses stress to 0.8 Pa and a displacement of $41.37x10^{-5}$ mm, figure 7 (b).

Finally, similarly to the backrest, the mathematical models of Storakers and Kelvin-Voight were inserted for the seat, using a constant density in the entire geometry of the component, and repeating the properties of Young's Modulus and Poison's ratio. At the end of the modeling, values of 0.4 Pa von Mises stress and $292.4x10^{-8}$ mm of total displacement were measured, figure 7 (c).

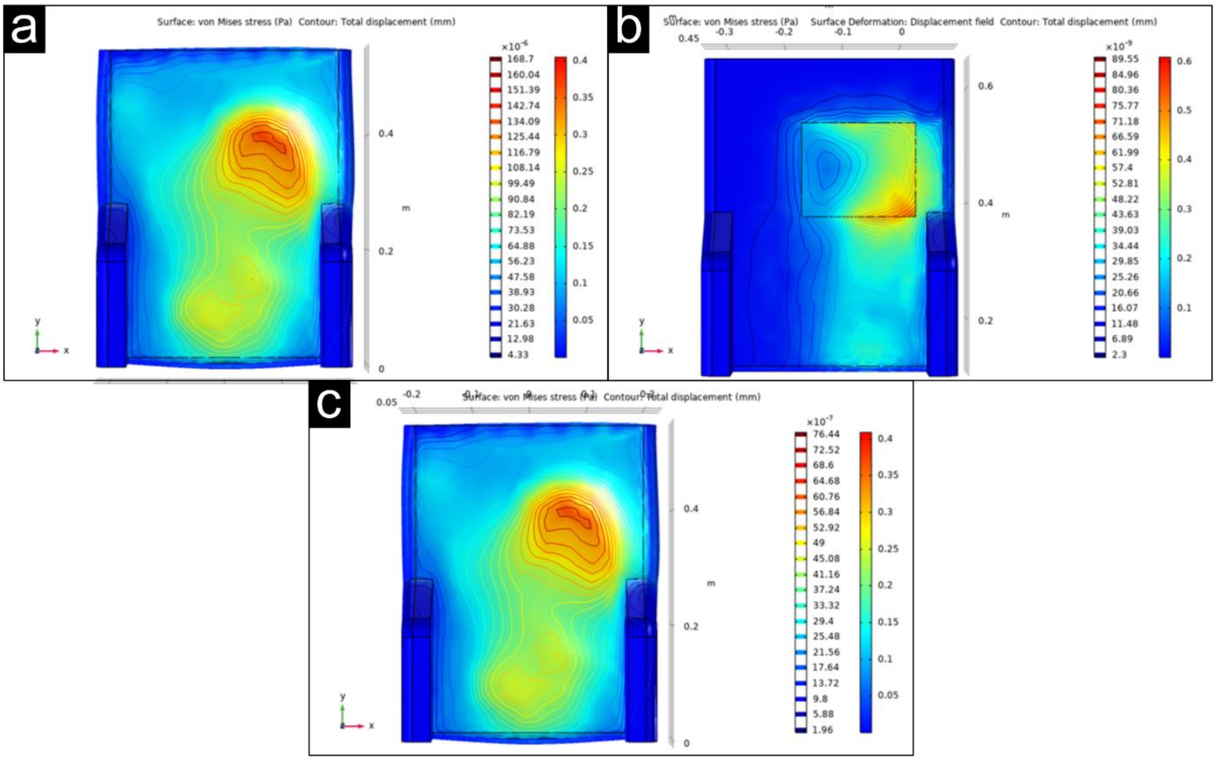


Figure 6. back system simulations results. a) linear elastic model; b) linear elastic model with different densities; c) viscoelastic model.

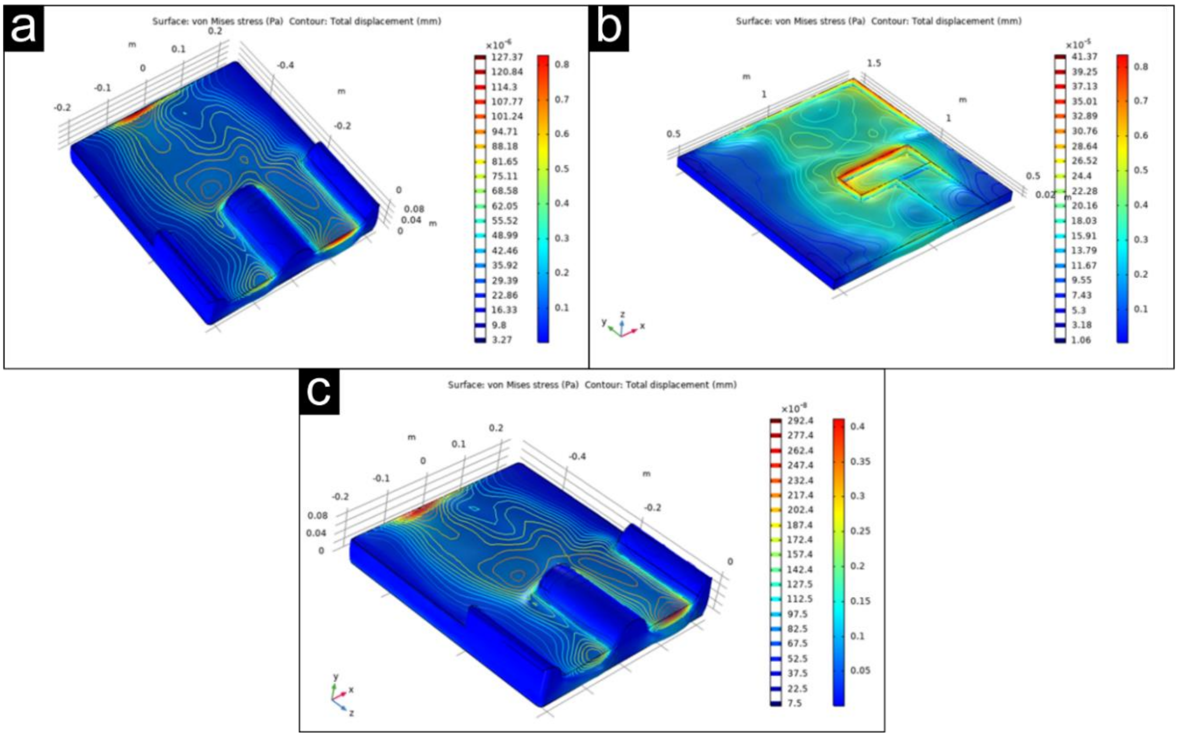


Figure 7. Seat system simulations results. a) linear elastic model; b) linear elastic model with different densities; c) viscoelastic model.

## 3 Conclusions

The results of the simulations were analyzed to identify critical stress concentration zones and high contact pressure in the actual seat-back system, which can possibly lead to bedsores and discomfort for the patient. The next stage of the project will be the formulation of an original Kelvin-Voight model of a viscoelastic seat-back system. This action line will take place since, to assist in the postural adequacy and comfort of children, it is necessary to have foams that have a low level of resilience.

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