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

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Abstract. One of the most compromised abilities in individuals who have neuromotor dysfunction is posture, requiring that most of them need to use some type of Assistive Technology equipment, for instance a wheelchair. This disorder can interfere with the insertion of the individual into society and impact his or her quality of life. The present work intends to develop low-cost seat-back systems focused on the children population with some kind of motor disability in the context of postural adequacy, and the numeric tools were used to give support for the development of new technologies. The thermography technique was used to create maps according to specific deformities of every child volunteer in this project. The temperature maps were converted into pressure maps and implemented as input data to perform numerical simulations in the Finite Element software COMSOL Multiphysics®. The computational analysis of different geometry cuts of polyester foams and their strategic positioning on the seat-back systems are also being studied to provide better distribution of the child body pressure on the system. Simulations show the potential of using octagon shapes of several foam densities to accommodate the deformations and to decrease the stress concentrations in the system.

Keywords: computational modeling; numerical simulation; wheelchair seat-back systems; postural adequacy; confort.

1 Introduction

Physical or motor disability can be considered a disorder of structure or function that interferes with the movement and/or locomotion of the individual, and may restrict their participation in school and work activities. According to the Brazilian Institute of Geography and Statistics, in 2010, of the child population, 7.5% of children aged 0 to 14 years had at least one type of disability, and of these, 1% had a motor disability (IBGE, 2010)[1]. These neuromotor dysfunctions end up compromising, in a more pronounced way, the skills related to their posture, making it necessary to use wheelchairs and impairing participation in daily activities, and may even result in pressure injuries and deformities. Therefore, it is necessary to develop specific seat-back systems to improve the postural control of children with motor disabilities.

There are currently some models of wheelchairs available on the market, but most of them have few or no adaptation to the patient's deformities, or are very expensive. In this context, this work has the objective to design new low-cost seat-back systems for wheelchairs, adapting to the morphology and needs of children with motor disabilities. These systems aim to improve comfort and correct posture, increasing the inclusion of these children within the educational system.

Several techniques were used to carry out the studies of this work, such as thermography, which consists of a non-destructive and non-invasive technique, which allows capturing images to determine the temperature of the components through the intensity of infrared radiation. The Finite Element Method (FEM) was also used, which is a way of predicting the behavior of materials through the discretization of the continuum, simplifying and allowing the calculation of the solution for complex structures. In addition, mechanical tests were conducted to obtain the material properties of the foams studied in this work. The use of FEM in simulations of seat-back systems has become increasingly used in the last few years. In the study of Grujicic (2009), FEM was used to model and simulate seat cushions and soft fabrics to increase the comfort of passenger vehicle seats [2]. Furthermore, it can also be mentioned the studies of mechanical behavior of seats with different materials, such as honeycomb (Jaworski, 2014)[3], air systems (Yu et al.,2021)[4] and polymeric foams (Kim et al., 2017)[5].

2 Methodology

In this study, thermal images of a patient were captured subsequent to their interaction with the back-seat system. These images were processed and utilized as input data, initially correlating the distribution of the highest temperature with the maximum contact pressure in the back-seat system. Computational simulations were conducted using the COMSOL Multiphysics® commercial software, in order to evaluate several foam geometries constituting the system. The objective was to determine which of these geometries will support and better adapt to the pressure distribution, thereby improving the comfort for the patients.

This work focused on a pediatric volunteer patient, specifically a child under the age of 12, who experiences motor disabilities due to the Zika virus syndrome. As a result of this condition, the child relies on a wheelchair for a significant portion of their daily activities.

2.1 Thermal Mapping

To obtain the thermal images, a FLIR T540 IR camera model was used and the procedure for obtaining the thermal images was standardized as follows. First, the patient is accommodated in his wheelchair and rests for 10 minutes. After that, the patient is then retired from the wheelchair and the thermal images are taken. Finally, these images are processed using Python. With the thermal mapping obtained, as presented in Fig. 1, it is divided into several ranges, forming different visualization levels of the patient's contact area with the system, as illustrated in Fig. 2.

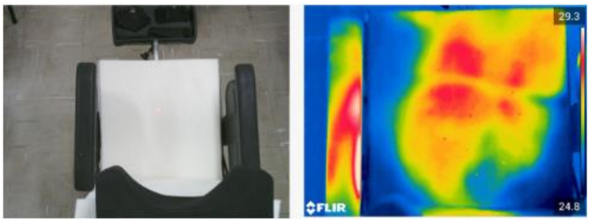

Figure 1. Thermographic image of the seat

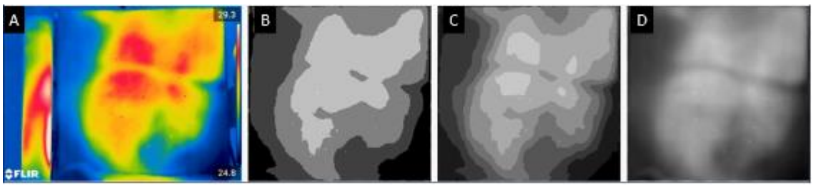

Figure 2. Segmented visualization levels of seat temperature data: A) original image; B) image with 5 temperature intervals; C) image with 10 temperature intervals; D) image with 50 temperature intervals.

2.2 System Geometry and Mesh Generation

The geometries were developed in the educational software AutoDesk Fusion 360, with the seat dimensions of 440 mm x 500 mm x 50 mm. For the new systems proposed in this study, the same dimensions were kept, but instead of using a single block (monoblock), the systems are formed by several blocks that together form the complete system. Two new system configurations were simulated, using cubic blocks and octagon-shaped blocks. The blocks have a dimension of 50 mm x 50 mm, except the last column with a measurement of 50 mm x 40 mm, as shown in Fig. 3. The dimensions of the octagons were based on the same dimensions, leading to a spacing between the octagons due to the shape itself. For the finite element modeling, the automatic extra fine generation of the software itself was used containing predominantly tetrahedral elements due to its suitability vs computational cost ratio. The total number of elements generated for the current system, modified system in blocks and modified system in octagons was, respectively: 30,412, 34,256 and 40,031 as shown in Figure 4.

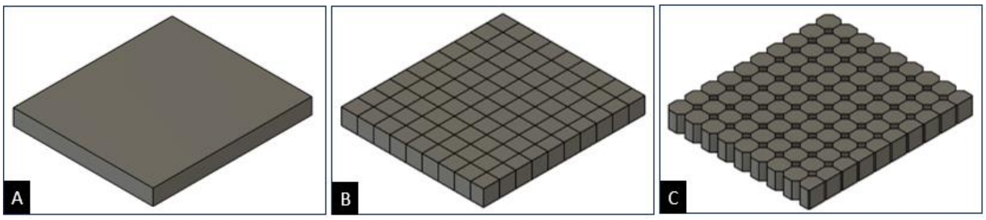

Figure 3. Geometry modeling: A) Current seat; B) Proposed seat in blocks; C) Proposed seat in octagons.

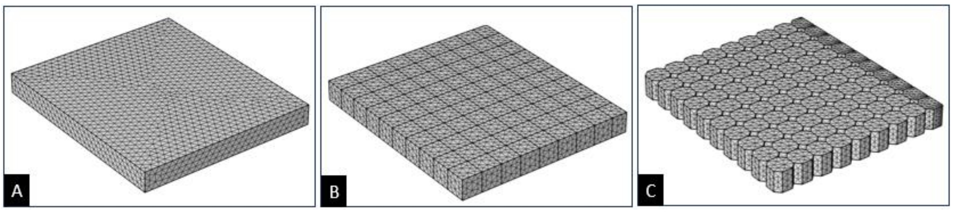

Figure 4. Mesh model: A) Current seat; B) Proposed seat in blocks; C) Proposed seat in octagons.

In order to perform the simulations, the elastic mechanical properties of the different foams studied were implemented. For this purpose, experimental compression tests were performed on 5 specimens of each foam and the average value obtained was considered. The mechanical properties are summarized in Tab. 2.

Table 1. Mechanical properties of each polyester foam

Mechanical property	**Name of the foam**			
	D33	**D28**	**D33**	**D45**
Density (kg/m³)	23	28	33	45
Young´s Modulus (kPa)	33.53 ± 4.45	33.74 ± 2.63	106.75 ± 25.10	236.45 ± 44.23
Poisson´s ratio	0.33	0.33	0.33	0.33

2.3 Results

Monobloc system

The first simulations were performed using monoblock foam systems, each one composed by only one density. Simulation results are presented in Fig. 5 and show that, as expected, the deformations obtained are larger as the foam density decreases. The maximum deformation obtained is 371.6 x 10-9 mm for D23 foam and the minimum deformation obtained is 52.69 x 10-9 mm for D45 foam.

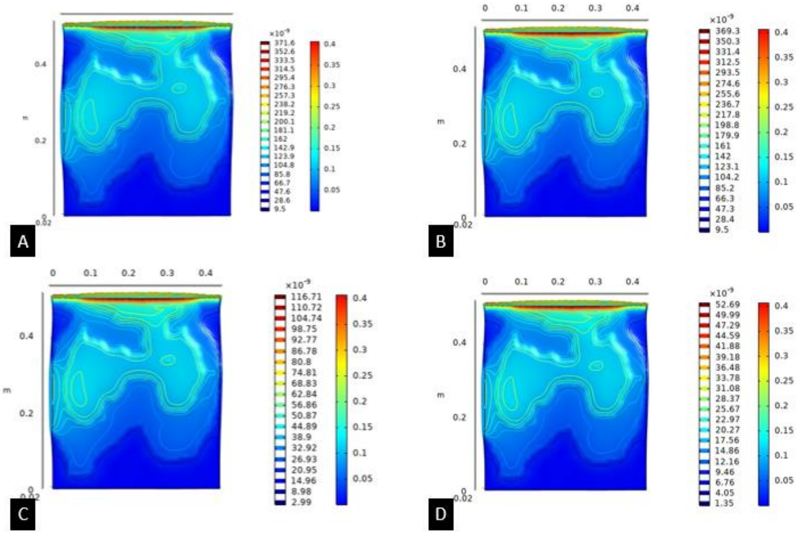

Figure 5. Simulation results of stress and deformation distributions in the seating system with the foams: (A) D23; (B) D28; (C) D33; (D) D45.

System with blocks of different densities

A preliminary new system was proposed, by using a set of blocks of different densities, substituting the areas with higher stresses and lower strains with blocks of lower densities. Thus, a seat of cubic blocks was built using the following densities: D23, D28 and D45. The simulations of the new proposed seat, presented in Fig. 6, show that the stresses decrease and the deformations increase, due to the better accommodation of the densities in relation to the load. In order to reduce the still quite visible stress concentrations, a second adequacy system was tested, this time using octagon-shaped blocks.

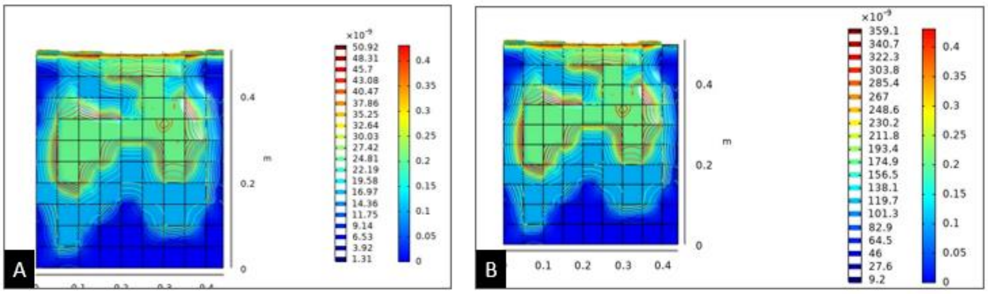

Figure 6. Simulation results of stress and deformation distributions in the seating system using the block seating systems: A) with density D45 only; B) with the densities D23, D28 and D45.

System with octagons of different densities

The methodology to study the second new system follows the same pattern used for the first suggested system. For the simulation only with the D45 density, we obtained a maximum von Mises stress of 0.45 Pa and a maximum total displacement of 50.07 x 10^{-9} mm that can be observed in Figure 7 (A). The simulation of the system formed by octagon-shaped blocks, the areas of greatest stresses were also replaced by foams D23 and D28, obtaining a maximum von Mises stress result of 0.45 Pa and a maximum total displacement of 348.3 x 10^{-9} mm, which can be seen in Figure 7 (B). In Fig. 7 we can observe that the stress distribution is more homogeneous, with lower stress concentrations in the seat, due to the greater accommodation and deformation of the foam octagons, compared to the monoblock system or formed by cubic blocks. Therefore, this type of geometry proved to be very promising to improve the comfort of children in the seating system.

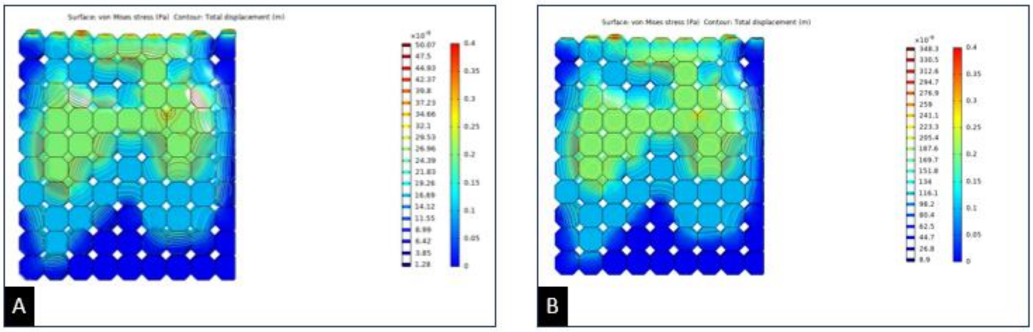

Figure 7. Simulation results of stress and deformation distributions in the seating system using octagons: A) with density D45 only; B) with the densities D23, D28 and D45.

3 Conclusions

The main objective of the present work was to study the possibility of developing new low-cost seat-back systems for wheelchairs, in order to provide a better postural adequation and increase the comfort, providing a better quality of life to children with motor disability. The result of the simulations and the analysis of the pressure and deformation distributions showed that it is possible to project and optimize, in an inexpensive way, new systems adapted to specific configurations of structured deformation of the body, allowing less discomfort for the patient using wheelchairs during a long period of time of the day. The next steps of the project are the manufacturing and testing of the new systems with the patients. Further works will also be performed to study new possible geometries, as well as other materials for manufacturing seat-back systems.

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