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ANALYSIS OF A NOVEL HEAD SUPPORT FOR PEOPLE WITH HYPERMOBILE-TYPE EHLERS-DANLOS SYNDROME

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INTRODUCTION

Ehler-Danlos Syndrome (EDS) is a group of heritable disorders that are characterized by abnormal collagen synthesis, leading to multisystemic connective tissue disorder. Six major types of EDS are recognized, the most common of which is the hypermobile type. EDS hypermobile-type (hEDS) is characterized by connective tissue laxity resulting in excessive joint mobility due to weak and less elastic ligaments and tendons.[1]

A particularly common symptom amongst people with hEDS is pain and instability in the neck. In hEDS, the extensive complex of cervical ligaments may fail to provide the normal support and endpoints for range of motion. This leads to muscle fatigue and pain.

Previous work has described the development of a head support for people with hEDS.[2] Interviews with people who have hEDS were conducted to identify desirable support characteristics and a new type of head support was developed and prototyped (Figure 1). The design consists of a polystyrene frame mounted to shoulder supports that are custom-molded to fit the user. The head support contacts the user's head at the occipital bone and on the bottom side of the mandible. The contact surfaces are covered with memory foam to provide cushioning and to allow the contact surfaces to mold to the user. A desirable design characteristic is the ability for the head support to flex in a controlled manner as the head is rotated. The support should allow a limited head rotation while also preventing excessive rotation which can lead to injury.

This abstract describes the development of a finite-element (FEA) model that can be used as a tool in the design of the flexible head support. The goal of the FEA is to accurately predict stress, deformation, and required neck torque as the user's head is rotated through a specified angle.

METHODS

A parametric, 3D solid-model of the current head support design was constructed in Autodesk Inventor using a top-down approach. The design is generated by creating references to a solid model of the user. Components are modeled using lofted surfaces that closely match the surfaces of the human model. This approach facilitates a highly-customizable design to provide a precise fit.

The FEA model is constructed using Inventor Nastran, which is tightly-integrated with the Inventor parametric modeler. This tight integration between the parametric modeler and the analysis package facilitates an iterative design/analyze/re-design process.

Figure 2 shows the FEA model of the head support, along with a "head surrogate" model that is used to model the user's skull and chin. The surrogate consists of chin and skull pieces that are rigid compared to the polystyrene components of the head support. The chin and skull pieces are connected to one another using a rigid-body connector that has a center of rotation located at the top of the C01 atlas of the human model. Contacts between the surfaces of the surrogate and those of the head support are modeled as separating surface contacts with a coefficient of static friction of 0.9. This relatively high coefficient of friction reflects the fact that the actual contacts consist of a rigid surface covered with a layer of foam that conforms to the user's chin and skull.

To simulate rotation of the user's head, fixed constraints are applied to the bottom surfaces of the strut mounts and a specified rotation is applied at the center of rotation of the solid connector. A

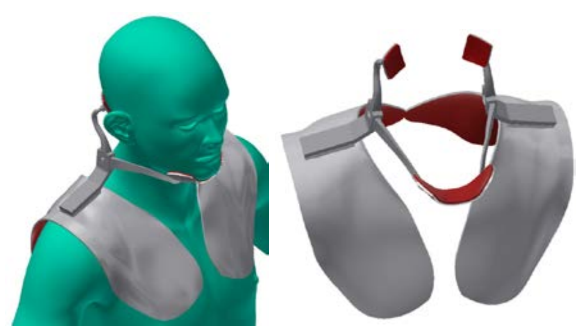

Figure 1: The head support modeled top-down using a solid model of the user.

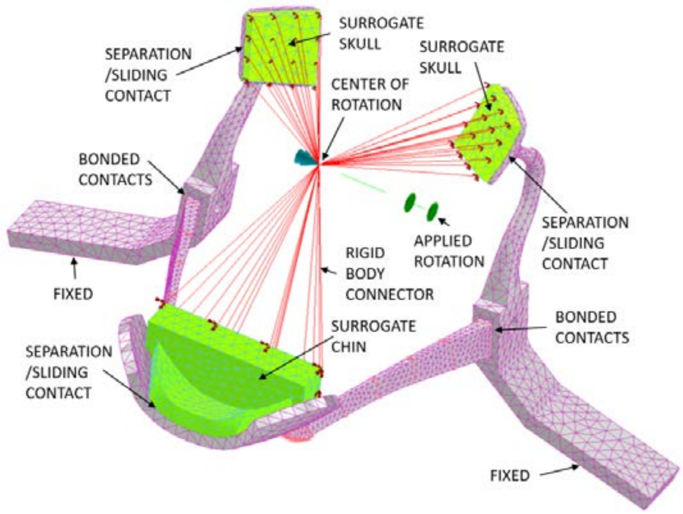

Figure 2: The FEA model of the head support with the head surrogate.

linear, static analysis is used as the head support material is intended to be used in the linear elastic region and the rotation angles used in these tests are relatively small.

The finite-element mesh is constructed from parabolic, solid, tetrahedral elements using the Inventor Nastran automeshing utilities, along with a set of user-specified mesh refinements. It is recognized that the head support contains components that might best be modeled using beam and shell elements, however a mixed-element model is more difficult to tie to the parametric solid model and does not lend itself to an iterative design approach.

Convergence of the Von Mises' stress and displacement at four different points on the head support was monitored as the mesh was refined. Points A-D shown in Figure 3, are located in areas where high stresses are generated by head rotations. Figure 4 shows that the stress created by a 2° lateral rotation converges as the mesh is refined. Mesh Iteration 7, which was used for all subsequent analyses, utilized a maximum edge size of 6.0 mm., along with refinements in the thin sections of the chin support and the filleted areas of the head support.

RESULTS

Figure 3 is a plot of the Von Mises' stress on the deformed mesh when the head surrogate is given a lateral rotation of 2°. The deformed shape shows the head pads and the chin support moving in the rotation direction as expected.

Table 1 lists the Von Mises' stress and displacement at Points A and B for increasing lateral rotations and extensions. The table also lists the torque required to produce each rotation. As one would expect, stress, displacement and required torque increase in a roughly linear fashion with increasing angle of rotation.

DISCUSSION

Work has been presented towards the development of a finite-element model that can be used in the design of a head support. The validity of the solid-element modeling approach was demonstrated for relatively small head rotation angles. It has been demonstrated that the model can be used to predict component stresses and deformed shape of the head support, and to predict the torque that must be produced by the user to produce a specific rotation.

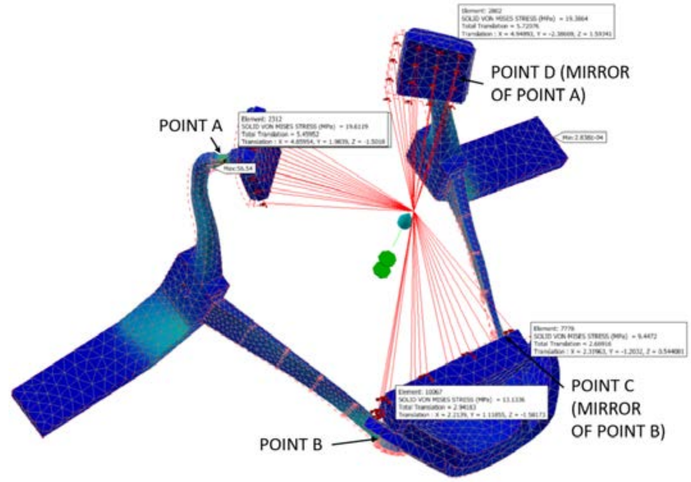

Figure 3: Stress and deformation resulting from a 2 degree lateral rotation.

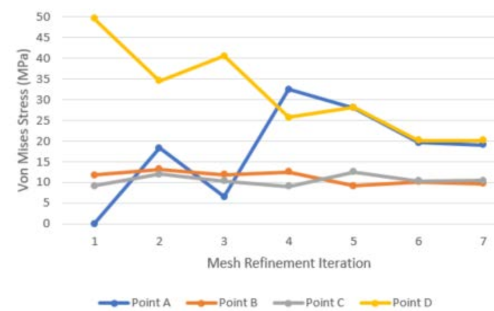

Figure 4: Convergence of Von Mises' stress as the mesh is refined.

Table 1: Stress, Displacement, and Required Torque for Increasing Lateral Rotation and Flexion Angles

	Point A		Point B		
	Von Mises' Stress (Mpa)	Displacement (mm)	Von Mises' Stress (Mpa)	Displacement (mm)	Required Torque (N-mm)
1° Hor. Rot.	9.3	2.8	5.5	1.3	5137
2° Hor. Rot.	19.6	5.5	13.1	2.9	10274
3° Hor. Rot.	47.5	8.4	17.4	4.3	17384
1° Flexion	3.4	1.4	3	1.9	2094
2° Flexion	6.3	2.8	6	3.9	4186
3° Flexion	9.5	4.2	8.5	5.8	6293

Future work will focus on expanding the validity of the model to larger rotation angles and on using the model to improve the design of the head support.

REFERENCES

[1] Bergmann, G et al., *J Biomech*, 34:859-871, 2001.
[2] Pierce, R. et al., "Design of a Novel Head Support for People with Hypermobile-Type Ehlers-Danlos Syndrome," *ASME J. Eng. and Science in Medical Diagnostics and Therapy, (accepted, in-press).*
[3] Adams, A., Askenazi, A., *Building Better Products with Finite Element Analysis*, OnWard Press, 1999.