EQUINE SCIENCE USING BETA CAE SOFTWARE

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KEYWORDS –
Equine science, ANSA, RETOMO, META, Abaqus

ABSTRACT –
The equestrian world is evolving and the interest for more ergonomic and durable equipment is growing. To fulfil this need, methods to validate, improve and design new equipment is crucial. The purpose of this project was to develop such a method, by the use of software from BETA CAE Systems. The target was to study the effects exerted by the bridle on the neck of a horse, as a starting point for developing the method. A simplified 3D (Computer Aided Engineering) CAE model of a horse neck was generated by using RETOMO-tool for segmentation of medical CT-scan images. The model was pre-processed and prepared for the solver Abaqus by built-in functions in ANSA. META post-processor was used to examine the results of the simulations, showing how stress spreads around the neck by identifying areas with higher and lower stress concentrations. The outcome of the simulations provides a numerical evaluation for understanding mechanical effects on the neck of the horse, exerted by the bridle.

TECHNICAL PAPER -

1. INTRODUCTION

For centuries, horses have played a major role in the daily life of humans, as a mean of transportation or as a work companion. Their strength made them valuable in many industries, as mining, logging and farming. In the military, a good horse could be vital for success in battle, as accounted in history books. It is from military activities many of the equestrian sports have developed. When horses started being replaced by machines, the role of the horse changed completely. Equestrian sports developed from being just a way to keep your horse in good shape to a global industry. The disciplines today include show jumping, dressage, eventing, racing etc., where three disciplines are currently represented in The Olympic Games.

As for any athlete, the equipment used is crucial. Equipment causing discomfort can be very stressful and result in both pain for the horse and lesser performance. The equestrian world is built on traditions and much of the equipment used today is based on convention rather than comfort. A change in the market is starting to show, where the interest for better and more ergonomic equipment is growing; an interest for equipment that gives the wanted performance while not hurting the horse. To develop this kind of equipment, it is crucial to find the right tools to create and validate the product. Knowledge from both, scientific and technical perspective, needs to be combined with knowledge of horse anatomy. A future aspiration would be to close the gap between engineers and veterinarians and together develop the most ergonomic and durable equipment for the horses.

This project aims to develop a method for computer aided research in this area. For years, FEA (Finite Element Analysis) has been used as a tool for computational studies in different areas. Our goal is to provide a method on how to build a 3D CAE-model of a horse, to be able to see how equipment affects the animal, something that to the best of our knowledge has not been done previously. The project has been limited to examine one part of the bridle, the piece that goes behind the neck of the horse, called *the headpiece* (see fig.1).

Parallel to the development of this method, we have also been doing measurements on living horses, to see the pressure exerted by the bridle on the neck of the horse. The results of these studies are not discussed in this paper.

Figure 1 A horse with a bridle on. The headpiece, bit and the reins are marked in the picture.

2. RETOMO TOOL SEGMENTATION PROCESS

RETOMO tool was used to create a 3D CAE model from medical CT-scans of a horse's head. First, the model was cropped to contain only the part of the neck that is affected by the headpiece. To save computational time during the simulation, the horse is considered symmetrical along the spine, therefore, the model was cropped along the symmetry line as well. The images contained some noise (fig 2a), which makes it harder to generate homogeneous materials, why the tool *Image smoothing* with strength 2 was used (fig 2b).

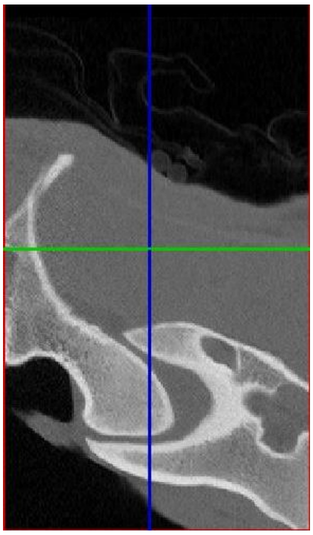

Figure 2a Before *Image Smoothing.*

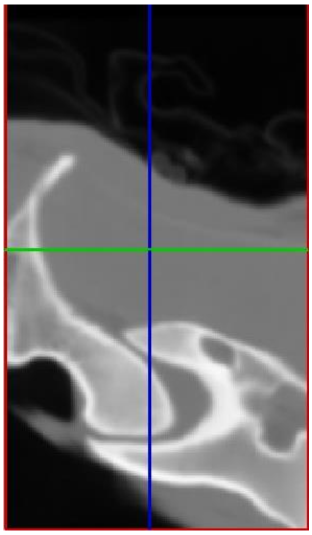

Figure 2b After *Image Smoothing.*

The image segmentation process in RETOMO was done in three steps, see RETOMO User's Guide (1) for details. First, the histogram, fig. 3, was used to set the boundaries between the materials. The model was simplified to consist of two materials, muscle and bone. In RETOMO, this meant that the model were to consist of three materials, since air is considered a material as well. The materials were separated by the intensity of the voxels. By changing the threshold in the histogram, the materials are defined. This can be visualized directly in the images, in fig 4a-b the limit for muscle and bone are shown respectively.

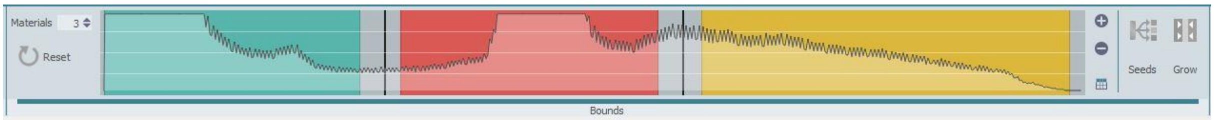

Figure 3 The RETOMO tools for segmentation of the medical images, including the histogram.

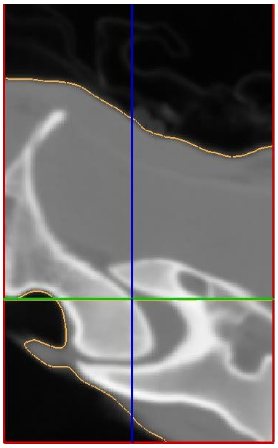

Figure 4a The outer limit defining the muscles.

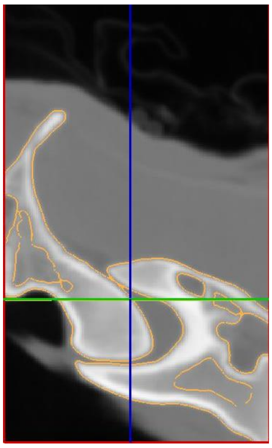

Figure 4b The outer limit defining the skeleton.

After the threshold process was defined, the coloured areas of the histogram were set to define the seeding area. During the seeding step, voxels that safely belong to a certain material was defined, see fig. 5a. This was done automatically by RETOMO, by looking at the intensity of the voxels, as well as, the region around the voxel. The last step in the segmentation process was the *growing* process, where the unidentified voxels were defined by their neighbors, see fig. 5b. Finally, a basic FE-mesh was generated and the model was ready for pre-processing, fig. 5c.

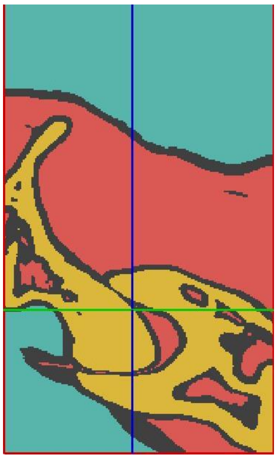

Figure 5a After the *seeding* process. The grey area are unidentified voxels

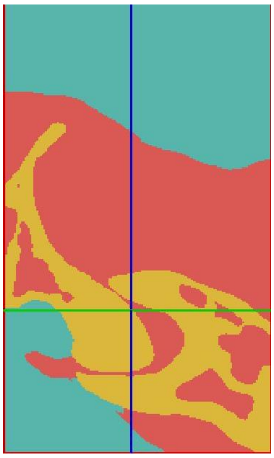

Figure 5b After the *growing* process.

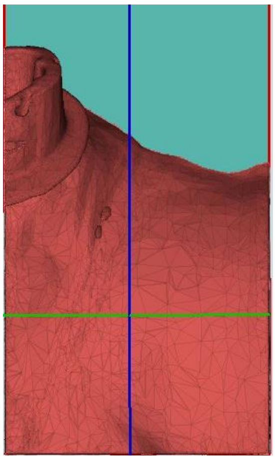

Figure 5c The basic FE-meshed CAE model.

3. PRE-PROCESSING

The CAE model created by the RETOMO tool was pre-processed and prepared for the solver Abaqus in ANSA. Below, the process is described.

Mesh

The mesh generated by RETOMO was not sufficient, why the tool *batch mesh* was used to generate a new mesh. The mesh generated was *solid structural mesh, 1st order trias,* with the mesh parameters and quality criteria used for the muscle and skeleton parts shown in Table 1. The unit group chosen for the whole model was mm, s, tonne (10^3 kg), N, MPa.

Table 1 The mesh parameters and quality criteria for muscles respectively skeleton.

Mesh Parameters	**Muscles**	**Skeleton**	**Quality Criteria**	**Muscles**	**Skeleton**
Target length	4	2.5	Aspect ratio	5	5
Minimum target length	3	2	Jacobian	0.7	0.7
Maximum target length	5	3	Min Length	3	2
Shells aspect ratio	5	5	Max length	5	3
Distortion angle	10	10	Min angle trias	20	20
Minimum length	3	2	Max angle trias	120	120

The mesh was cleaned by checking and fixing these errors:

- Intersections
- Interior intersections
- Triple bounds
- Single bounds
- Sharp edges
- Negative volumes
- Abaqus checks

After this, a volume mesh was generated. The elements used were C3D8H, *"H"* in the element identification stands for *hybrid* elements, which are necessary when dealing with hyperelastic and incompressible or nearly incompressible material behavior. The reason for using hybrid elements is due to the muscles being modelled as a hyperelastic material.

Materials

The material models were created from experimental data collected from Chen et al. (2), Shahara et al. (3) and Ahsman et al. (4). Ideally, bone and muscles from the neck of a horse would have been tested to obtain the right parameters, instead, data from experiments on bovines were used for the material model of muscles. As for the material model of the skeleton, experimental data of the human femur bone were combined with data from tests on equine cortical bone.

Muscles are often considered a hyperelastic, nearly incompressible (Poisson ratio > 0.49), material when loading conditions are static or quasi-static (Ansari et al. (5)). Three different hyperelastic material models were considered; Ogden (N=3), Polynomial (N=2) and Yeoh. Using the least-square method, curve fitting of a stress-strain curve of the Latissimus dorsi muscle of bovine was used to find the parameters needed for the material models. Only two of the models, Ogden and Yeoh turned out to be stable. The stress-strain curve is shown in fig. 6 and the material properties calculated for both material models are shown in Table 2.

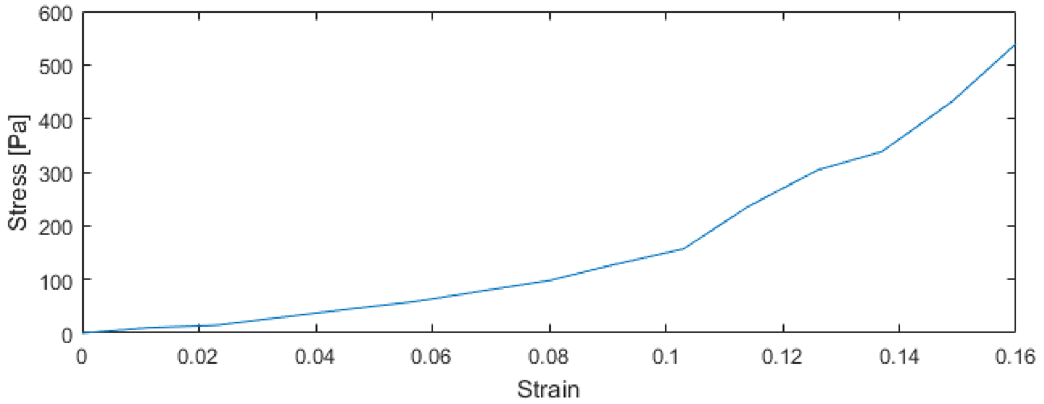

Figure 6 Stress-Strain curve for compression of bovine latissimus dorsi muscle, Chen et al. (2).

Table 2 Material parameters for muscles, Ogden and Yeoh.

	Ogden Model			**Yeoh Model**	
i	**μ_i**	**α_i**	**D_i**	**C_{i0}**	**D_i**
1	-1.369e9	1.971	1.035e-4	151.508	1.329e-4
2	9.121e8	3.886	0	-1.690e8	0
3	4.573e8	−1.859	0	8.610e13	0

To create material models for the skeleton, a linear elastic, orthotropic model was used. The material was defined by nine independent elastic stiffness parameters, given by experimental data from compression of equine cortical bone in Shahara et al. (3) and human femur bone in Ashman et al. (4). The equations for converting Young's Modulus, Poisson Ratio and Shear Modulus to Abaqus input parameters can be found in Abaqus Analysis User's Manual (6).

Contacts

To define contacts between the skeleton and the muscle parts, ANSA-Abaqus Contact Assistant was used. The contacts were defined as *tie* contact, with friction coefficient 0.3 (Shacham et al. (7)) between the master (the muscle part) and the slave (the skeleton part).

Boundary Conditions

The back and the bottom of the model were set to be fixed, the front was set to be free to translate in the x, y, z –directions and the symmetry side was set to be free to move in the y, z –directions, but fixed in the x-direction (normal to the side) due to symmetrical boundary conditions. In fig. 7a-d the boundary conditions of each side are shown. The numbers symbolize the fixed directions, 1: x-translation, 2: y-translation, 3: z-translation, 4: x-rotation, 5: y-rotation, 6: z-rotation.

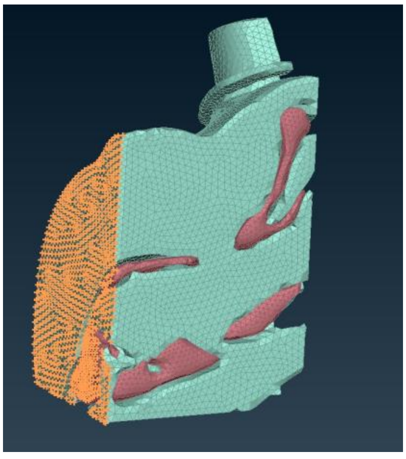

Figure 7a BC back: 123456

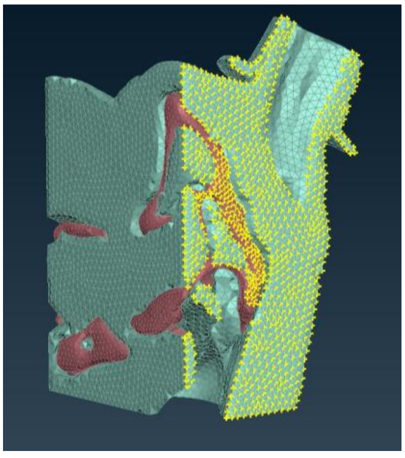

Figure 7b BC front: 456

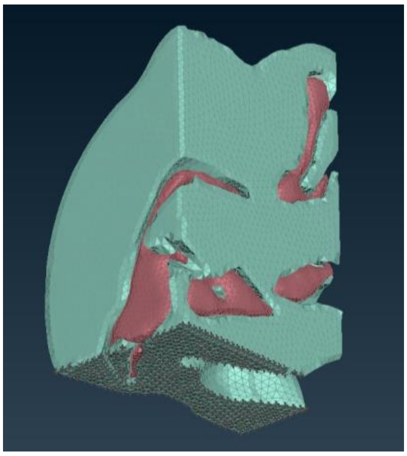

Figure 7c BC bottom: 123456

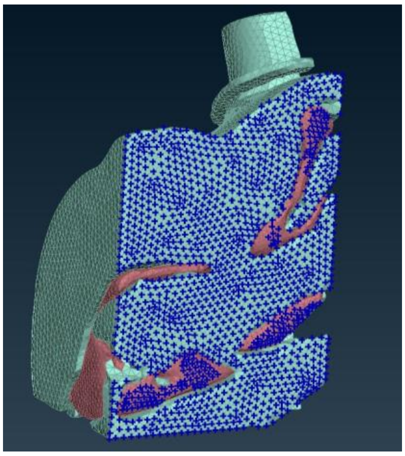

Figure 7d BC side: 1456

The headpiece

To understand how the headpiece is to be simulated, one must first consider the nature of the load exerted by the headpiece. The load depends on how hard the bridle is tightened, how much force is applied in the reins by the rider, which bit is used, how the neck of the horse is bent etc. If the dynamic behaviour of the load is to be considered, a viscoelastic material model is necessary. Such models require the same information as the hyperelastic material models, but with some added time-dependent parameters. By considering the load quasi-static, and solving for different quasi-static loads, it is possible to model the system in a proper way, however, with a much simpler material model.

To simulate the load exerted by the headpiece, a distributed load over the affected area was used, see fig. 8. The distributed force applied was chosen as the mean value from the measurements done parallel to this project and set to 4 N distributed over the affected area.

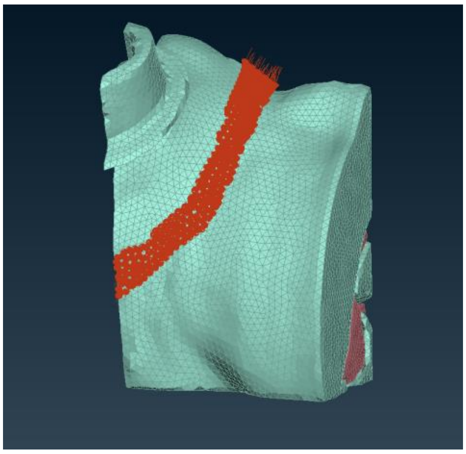

Figure 8 The distributed load on the neck.

4. SIMULATION AND RESULTS

In order to analyse the stress distributed in the neck, simulations were performed in the solver Abaqus for two different types of material models for the muscle of the horse: Ogden (N=3) and Yeoh. The contacts, loads etc. were defined as listed in section 3. The results were analysed using META post-processor, and are shown in fig. 9 and 10.

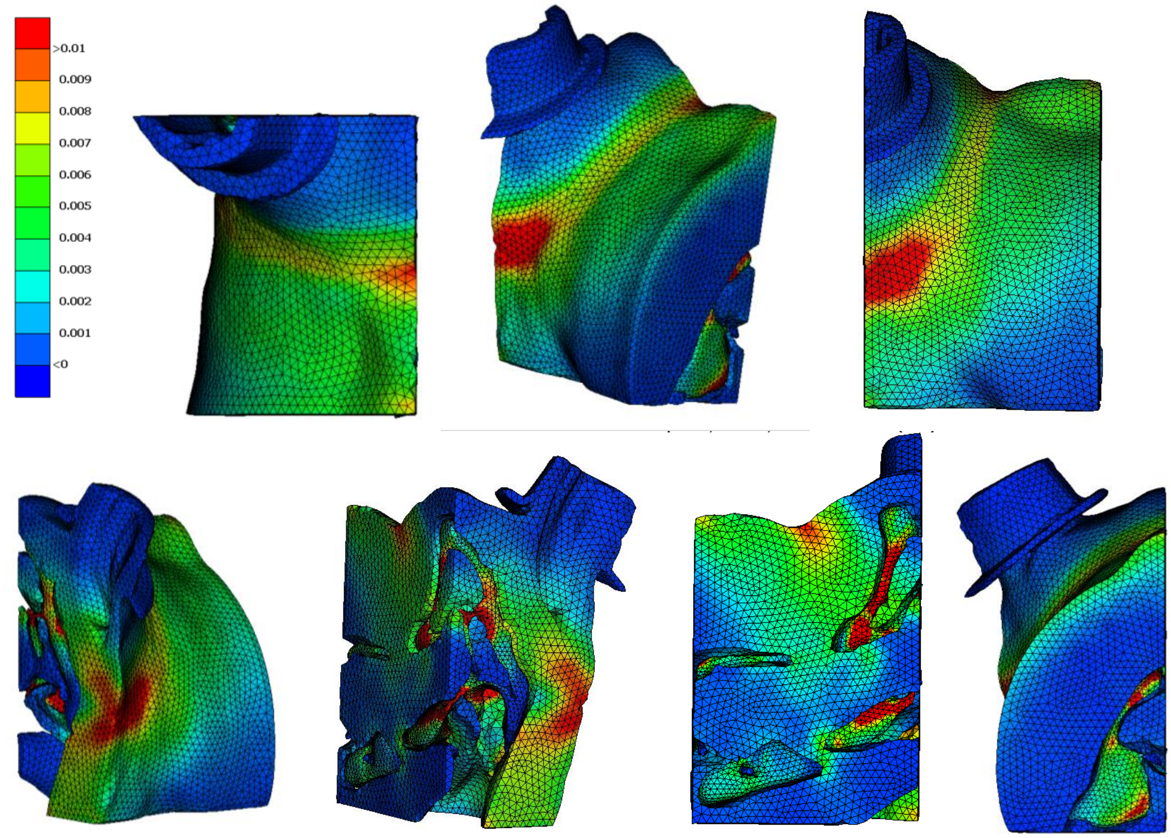

Figure 9 The von Mises stress distribution for Yeoh material model. The unit of the colorbar is MPa.

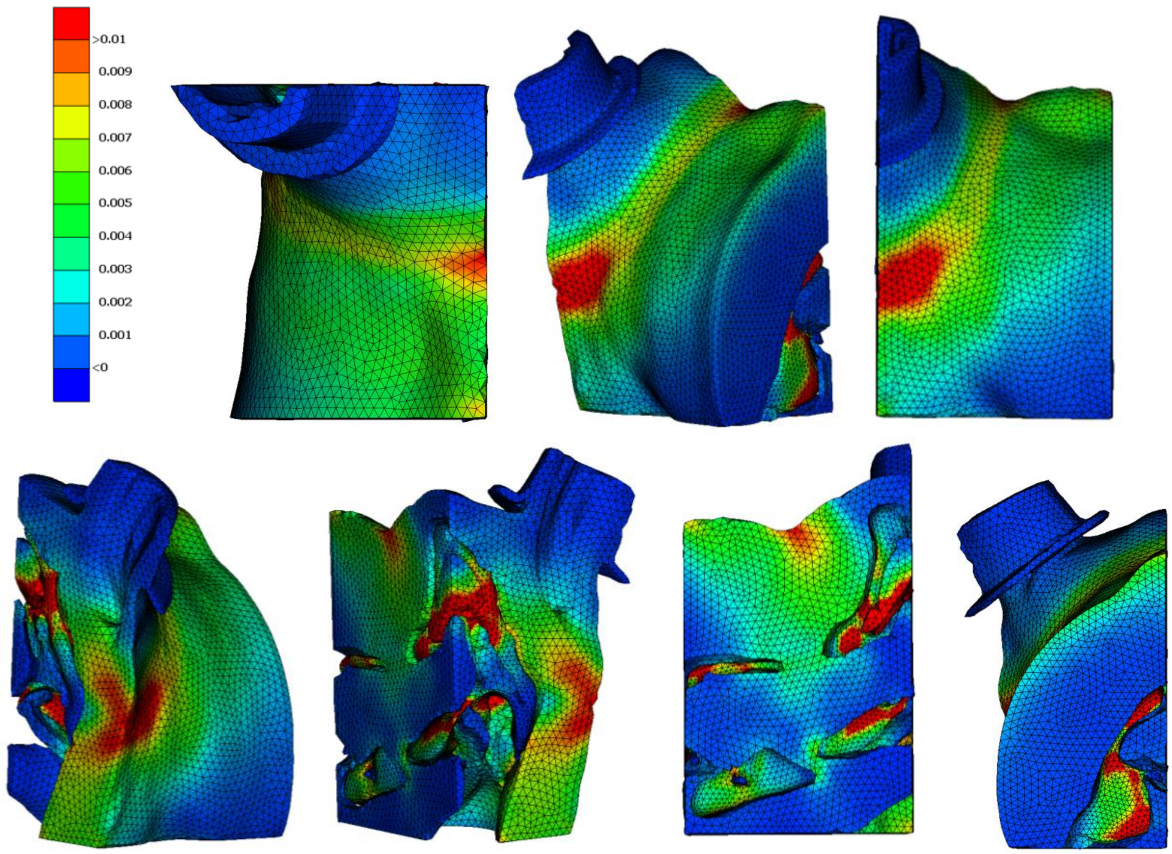

Figure 10 The von Mises stress distribution for Ogden material model. The unit of the colourbar is MPa.

5. DISCUSSION

As can be observed in fig. 9 and 10, the von Mises stress distributions are very similar for the two different muscle material models. This indicates that, for the experimental data used to obtain the material parameters, the two material models provide similar results and can both be used as good candidates for modeling muscles as hyperelastic, nearly incompressible materials.

The results show that the stress spreads from the muscles to the skeleton, which indicates that defining the contact between muscle and skeleton as tied may be a good approach in order to model the interaction between the two parts.

To improve the model, studies on the material properties of equine muscles and bones are needed to develop the material models. It is also recommended to evaluate which contact definition between muscle and skeleton that would give the most realistic result.

As for how the comfort of the horse is affected, high stress in the neck area is undesirable. Tension in the neck of the horse can spread down the spine and through the back of the horse, which can lead to the horse being stiff. The model developed in this project can be used to design better headpieces, preferably headpieces that distributes the load in a better way.

6. CONCLUSIONS

In this project we have developed a new way to examine mechanical effects on horses and in this paper we have presented a protocol for such studies. We have described the process of going from medical images to a ready to run FEA model. There are several ways to improve the work, including more accurate material models (collecting experimental data from equine muscles and bones), as well as, creating CAD model for the equipment.

Models like this one could be used to design, improve and test equine equipment, something the market calls for. For example, for a long time, veterinarians have been concerned by damages in the mouth of the horse generated by bad designed bits. By the use of a well-designed model, FE-analysis may be a great tool to examine this problem. We strongly believe that methods like the one discussed in this article can be very valuable for the development of equine equipment.

ACKNOWLEDGMENTS

This work is supported by Chalmers University of Technology, Area of Advance Materials Science. We are very grateful to BETA CAE Systems for providing us with excellent help and education. We would also like to express our very great appreciation to veterinarian Åsa Hinton for her valuable and constructive suggestions during the planning and development of this research work. Dan Brase and Autoliv who kindly let us use their equipment for the pressure test parallel to this project. The knowledge of Hosein Naseri, Karin Brolin and Johan Davidsson from Chalmers University of Technology Area of Applied Mechanics has been of great help when developing the material models. We are also very thankful for the medical scans received by Evidensia Horse Hospital Helsingborg and Swedish University of Agricultural Sciences.

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