EVALUATING CONTACT MECHANICS OF CERVICAL COLLARS WITH FINITE ELEMENT AND PHYSICAL MODELLING

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Introduction

Cervical collars provide external support to the upper spine, aiding rehabilitation and reducing the risk of damage. The mechanical loading that cervical collars put on the skin causes discomfort, pain, and damage in the form of pressure ulcers [1]. Pressure in combination with shear loads poses an especially high risk [2]. Measurements of interface mechanics have been limited to normal pressures, measured at discrete points across the interface. Distribution of pressure, pressure gradients, and shear stresses are thought to be just as important as the peak pressures but have not been evaluated for cervical collars. To date, there has been limited design innovation through bioengineering approaches to improve device design and interfaces.
This study aims to evaluate cervical collar design through observed and predicted contact pressures at the device interface through finite element (FE) modelling and a physical phantom model evaluating a common extrication cervical collar (Stiffneck Select).

Methods

A finite element and in vitro physical model were developed to evaluate the application of the rear of a cervical collar onto a phantom head shape. The NIOSH medium head shape was used for the phantom physical head and the FE model geometry. The FE model (Figure 1A) includes a uniform soft tissue with a thickness of 8 mm and linear elastic modulus E = 200 kPa, ν = 0.45. The collar was modelled with linear elastic shell elements for the stiff support material (E = 600 MPa, ν = 0.3). A first-order Hyperfoam model was fitted to material test data for the foam padding. An isotropic Coulomb friction model was used with a coefficient of 0.6 for the collar-skin interface. The collar was pulled from either side onto the head. This was replicated in the physical model with pressure recorded at the device-skin interface in key locations across the upper and lower contact regions—a load cell monitored tension in the straps.

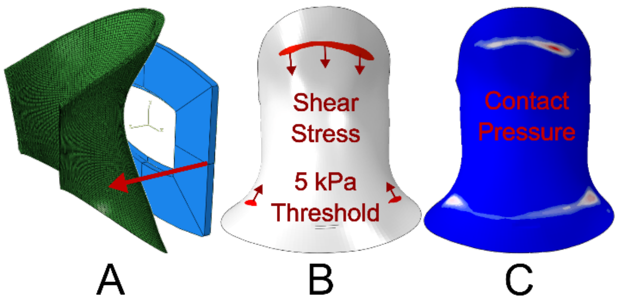

Figure 1: A) FE model setup, B) FE Contact Shear, C) FE Contact Pressure at 15 N tension

Results

Contact between the collar and head was predominantly across the top and bottom edges (Figure 1C). This moved towards the vertical centerline of the collars as more tension was applied and the collar foam deformed. Interface pressure increased with higher tension for both FE and physical models. Contact pressure values were in a similar order of magnitude according to strap tension between FE and physical model testing, though the FE model generally underpredicts the interface pressures (Figure 2). Significant shear stresses were present across the top, pulling the skin down, and on the shoulders, pulling the skin up and inwards (Figure 1B).

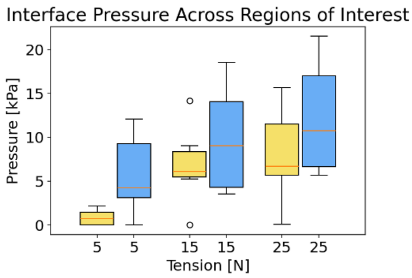

Figure 2: Pressure in key regions for FE (yellow) and physical (blue) models

Discussion

This study presents the first step in developing an FE model for a preclinical in-silico evaluation of cervical collar design. Pressure values match well with physical modelling. The FE model gives insight into the distribution of pressures across the contact area, showing the areas at risk of damage. Much of the contact is seen to experience shear stresses above 5 kPa. It is widely understood that shear stresses harm skin health [2]. However, the tolerance of skin to shear stress is not well understood.
While these specific results have limited generalisability, future developments will evaluate collar fit across a population of head shapes and collar designs. This will enable the evaluation of new collar designs to better suit the needs of all users and help reduce device-related pressure ulcers.

References

1. Brannigan et al. Global Spine Journal, 12:1968-1978, 2022
2. Gefen et al. Journal of Wound Care, 29:S1-S52, 2020

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