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Comparing Boundary Conditions on Hybrid Biomaterials Using Computational Analysis

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Abstract

Scientists integrate the mechanical qualities of creating biological materials with their immunomodulatory properties to advance biomaterial technologies. In this study, three different boundary conditions are used to assess the biomechanical characteristics of leporine skin in terms of stress, strain, and stretch. By using Ansys Mechanical APDL, the improvised dog-bone dimension was created. Using the Odgen and Neo-Hookean hyperelastic models, the specimen was identified as a non-linear material. After applying the parallel forces to the x-axis, 30-degree angle, and two separate categories of Ogden parameters, the results turned to $\mu = 0.048$MPa, $\alpha = 7.073$ for Anterior-Posterior (AP) while $\mu = 0.020$MPa, $\alpha = 9.249$ for Dorsal-Ventral (DV). At the end of the simulation, the specimen elongated at F_1=14N, F_2=27N, F_3=40N, F_4=54N, F_5=67N, and F_6=80N. The stress-stretch curves thus show that the angle of orientation affects the biomechanical parameters and that Anterior-Posterior (AP) has a higher stretch ratio than Dorsal-Ventral (DV). Technically, the outcomes showed how varied boundary conditions affected the laporene skin once the initial stresses were applied. Future applications include animal dermatology, hyperelastic modelling, and soft tissue analysis.

Discipline: Biomaterial, Biomechanics, Engineering, Mechanical Engineering, Biology

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1 Introduction

Through the implantation process, biomaterials are substances made from natural or synthetic sources that are utilised to replace, enhance, or treat tissues, organs, or biological processes (Dorrepaal, 2018). As a result, biomaterials must meet certain requirements in terms of strength, durability, and biological influence for a variety of applications (Alizadeh-Osgouei, 2019). Understanding the properties of biomaterials is necessary for finite element analysis to produce a precise model. The shear modulus constant and strain hardening constant are two important biomaterial properties (MPa). During the pre-processing stage of ANSYS, we should introduce either an Ogden or a Neo-Hookean parameter. The data must also be analysed to ensure that the biomaterial's mechanical behaviour supports its suitability for use in biomedical applications (Oladapo, 2020). Finite element analysis (FEA) is the ideal method to replace in vitro and in vivo experimental procedures due to the complexity, high expense, and risk of testing methods. The ability to recognise the behaviour of intricate systems or models is another advantage of this approach. FEA has been utilised and proved in predicting structure and calculating vertebral strength in a range of circumstances since its introduction in the field of biomechanics decades ago (Takano, 2017). Additionally, the FE programme can simulate procedural tests in order to model biomaterial deformation. Computer analysis is a reliable tool for assessing biomechanical features in hyperelastic models, including two Boundary Conditions (BC), stress-stretch figures, and elongation load.

2 Literature Review

2.1 Hybrid Biomaterials

Next-generation biomaterials, according to Costa, combine bioactive and bioresorbable properties to stimulate in vivo tissue regeneration pathways, promoting the body's ability to heal itself and facilitating the replacement of the scaffold with regenerated tissue (Costa, 2007). Synthetic and natural materials combined to create hybrid biomaterials that mimic the mechanical properties of the tissues or organs they are replacing while also possessing immunomodulatory effects. In tissue engineering, biomaterials are frequently used to create heart valves, blood arteries, and human bone tissue. It has mechanical qualities that can withstand any internal pressure the body may experience. In a circumstance comparable to this, hybrid biomaterials used to create artificial skin need to be compatible with human skin. The genetic makeup of other material specimens like leporine skin is most similar to that of human skin. Leporine skin also referred to as rabbit skin, belongs to the rodent group.

2.2 Hyperelastic Constitutive Models

The analysts always have the same goal in mind, as they use different methodologies and hyperelastic fabric models to determine the mechanical properties. Ogden, Mooney-Rivlin, Neo-Hookean, Green hypothesis, and others (Wang, 1997) were the most widely used models for computational analysis of specific biomaterials (Christensen, 1982). These days, the main goal of computer innovation is to create building programmes that will help analysts predict forward. As a result, bundles of hyperelastic fabric are widely used in FEA computer programmes to enable more accurate fabric testing. In fact, the input to carry out restricted component research will have a variety of features and components based on the hyperelastic exhibit required inputs.

2.3 3D Modelling by ANSYS

This article discusses an effort that produced a straightforward 3D model for use in Ansys programming to acquire biomaterial deformation and removal with high accuracy by using the constraints for Odgen and Neo-Hookean from earlier experts. Additionally, nonlinear hyperelastic can be defined and the model can be fitted into components by promoting the growth of a 3D model. As a result, if it is successful, comparable response structures may be accepted and we may have a better computational knowledge of the response. In this context, the Odgen and Neo-hookean models that have been constructed can be used to study the responses of biomaterials with varied borders and under different limit conditions without the need for actual investigation. This review also aimed to demonstrate the non-direct and anisotropic effects of leporine skin. Due to its flexibility, delicate tissue or skin's non-direct conduct should exhibit considerable pressure bends, demanding a careful inspection of the strain to more clearly distinguish the nonlinear conduct (Houlsby, 2019).

3 Methodology

3.1 Case Study and 3D Modelling

The investigation involves utilizing a limited component approach to determine the biomechanical properties of leporine skin. The steps of computational examination techniques are separated. The basis for this study was an experiment focusing on methods to define the traits of leporine skin; notice that, unlike human skin, leporine skin is covered with fur. The cycle of building model math at that time was followed by replication in constrained circumstances, which was followed by an evaluation of the data and a discussion of the reproduction. It is normal to practise using a dog bone model created in compliance with International ASTM (D2209-00) for standard testing procedures for calfskin elasticity (Pandit, 2007). Using Ansys, it was demonstrated that the leporine skin had the exact same appearance as a dog bone with dimensions of 171 mm in length, 31.8 mm in width, and 7 mm in thickness. Given that it is a biological skin, the thicknesses are uneven and are often estimated at 7 mm.

3.2 Material Parameters

Based on the outcomes of the tensile tests, the boundaries for the FE model of leporine are not set in stone. Previous studies on delicate tissues have shown that both human and animal skin is mechanically complex (Manan, 2018). Hyperelastic models were utilized in this research to represent all of the properties of delicate tissue or skin, including non-direct pressure-strain connections, time-dependent behaviors, incompressible, anisotropic, and inhomogeneous behaviour, due to the complexity of the behaviour (Eemeren, 2013). To define the exact properties of leporine skin, two hyperelastic models were used which are Odgen and Neo-Hookean models. For Odgen's material coefficients used in finite element analysis to be ($\mu = 0.048$MPa and $\alpha = 7.078$) for Anterior-Posterior (AP) while ($\mu = 0.020$MPa and $\alpha = 9.249$) for Dorsal-Ventral (DV). Whereas the Neo-Hookean model coefficient has the same values for AP and DV which are ($C_1 = 0.216$ and $D = 0$). All the coefficient values were selected based on the data and outputs of the experiment in Table 1.

Table 1: Coefficient values from hyperelastic models.

Hyperelastic model		Skin categories	
		AP	DV
Ogden	μ (MPa)	0.048	0.020
	α	7.073	9.249
Neo-Hookean	C1 (MPa)	1.128	0.216
	D	1.537	0

3.3 FEA Model Development

Figure 1 illustrates how the 3D models were integrated utilising 3D 8 hub underlying strong independently into 185 hubs and 80 components. 185 skin component hubs were displayed to highlight the lengthening and deformation of each hub. In this way, it is possible to comprehensively analyse the pressure-strain and stress-stretch relationship of nonlinear material for leporine skin while considering the change for the hubs x, y, and z.

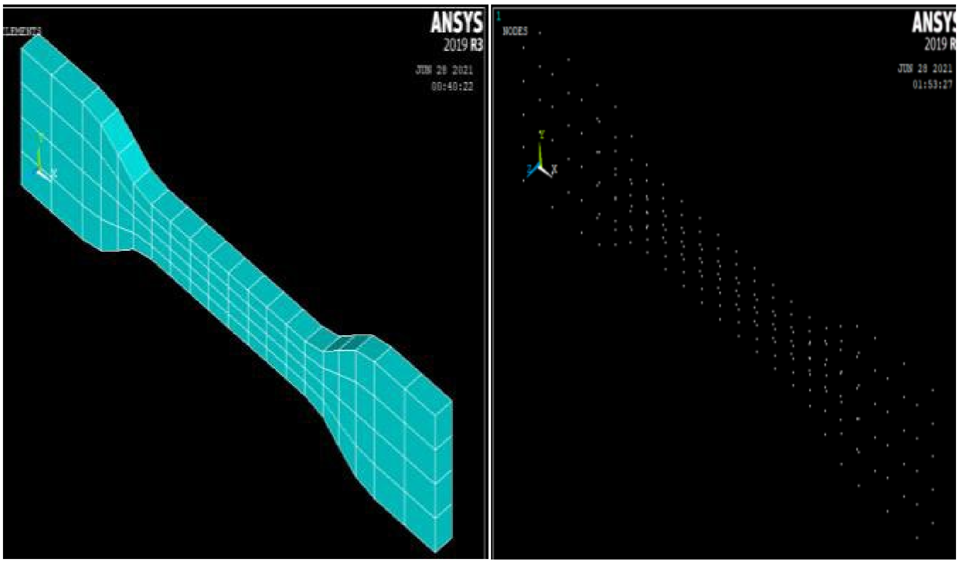

Figure 1: The meshing stage and nodal displacement.

3.4 Boundary Conditions

After the FE model with properties, such as a 3D strong principal with network 185 hubs and 80 components was built, the heaps and limit conditions for the uniaxial pliable test using Ansys were selected. Both hyperelastic models were investigated for the first limit condition (first BC) and second limit condition (second BC) (second BC). In this evaluation, the tractable inquiry structure was used to apply the piles and limit criteria. Whether the DOF is vital if in UX, UY, and UZ at the end left half of the model and the heap was applied in accordance with the x-hub is the main limit requirement that is taken into account in Figure 2. The fundamental of each of the three pivots has zero features at the model's beginning point, which has been fixed. On the hubs, an appropriated heap of 14N was put after one additional side of the model (191,190,189,187,134.135,136,137 and 138). After that, the cycle was repeated with loads applied (14N, 27N, 40N, 54N, 67N and 80N). Figure 3 illustrates the following limit condition, which allows for the model's end left half in UX, UY, and UZ while applying the heap at a point of 30 at the x-hub. The benefits of applied burdens and benefits of the major limit condition are the same.

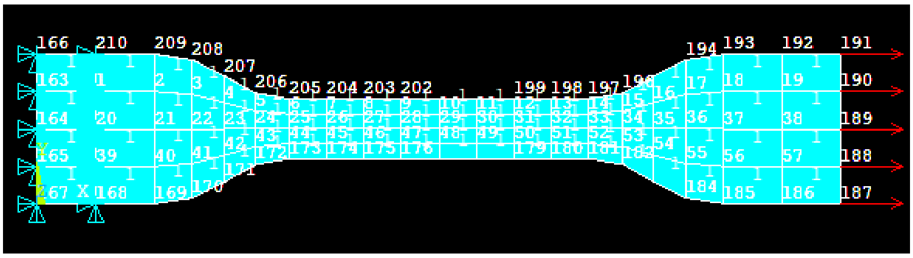

Figure 2: The applied loads and BC in tensile mode.

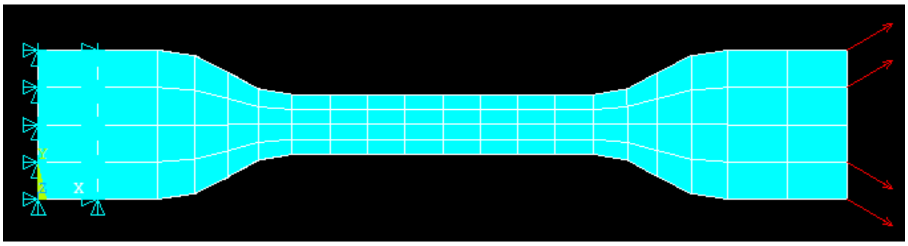

Figure 3: The second boundary condition used in FE analysis.

3.5 FEA Execution

To demonstrate how well the shape transformed and twisted as the work advanced, the FE model was also placed through a manageable test simulation. The model was dissected under intense static uprooting since the inspection choice with time control is zero. All arrangements were considered in this simulation (including nodal DOF arrangement, component nodal load, component nodal stresses, and etc). Under the nodal DOF configuration, the expansion or removal of hubs x ways was calculated. Using ANSYS' Outcome Watcher, Figure 4 shows the reenacted deformity and removal form (uniaxial lengthening).

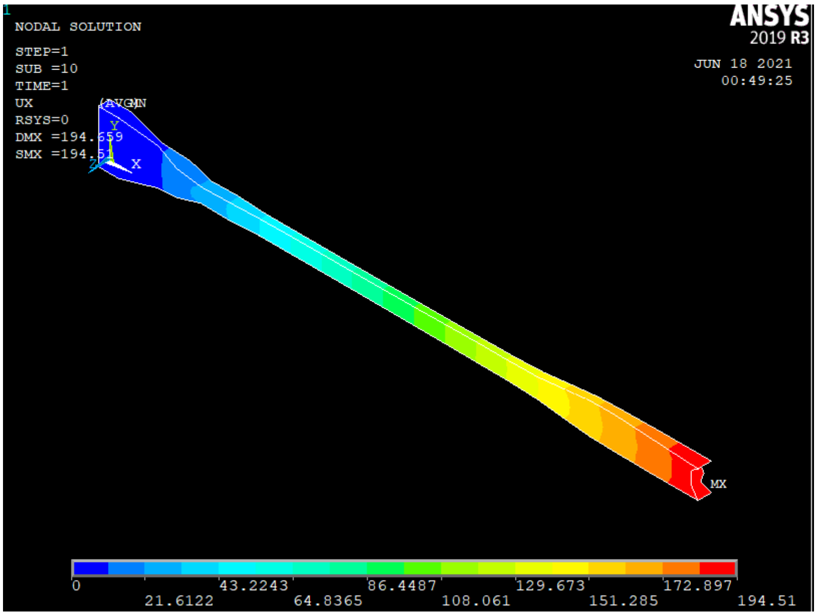

Figure 4: Example of simulated deformation and displacement contour.

4 Results and Discussion

Regular skin properties have been effectively investigated computationally, and the results satisfy the objectives. The outcomes of the nodal relocation esteem simulation will help with the research of basic mechanical properties (stress, strain, and stretch) as well as biomechanical qualities (hyperelastic model constraints) for normal skin. Using the (2 planes) from an XY view, the consequence of mutilation and uprooting shape from the Odgen model and Neo-Hookean model is depicted.

4.1 Biomechanical Properties

Using the information investigation approach, the findings of the ductile test reproduction were converted into a mechanical quality of biomechanical characteristics (for instance, stretch), and were then arranged and displayed in Table 2, Table 3, Figure 6, and Figure 7. With two subcategories of leporine skin for the pressure stretch worth—AP and DV—Figure 6 shows the pressure stretch bends for two classifications of limit conditions: power corresponding to x-pivot and power at 30 corresponding to x-hub. The pressure stretch bends illustrated for each class of limit condition, except the Neo-Hookean bend, seem to demonstrate that the Odgen model generates the massive pressure stretch bend pattern of hyperelastic. According to the research, Odgen has the lowest stretch of the five bends, while Neo Hookean has the largest stretch. This suggests that Odgen is more flexible than Neo-Hookean and lower than attempt.

According to the graph in Figure 6, leporine skin under power with 0 points of direction (equal) stretches more than skin under power with 30 points of direction. When comparing the AP and DV classes, the findings indicate that AP has a higher stretch value than DV, as seen in Tables 2 and 3. As a result, when compared to DV, AP might be perceived as more grounded. This viewpoint allows us to deduce that the skin's biomechanical qualities are likewise influenced by its class. According to Manan (2015), the skin's material limits are thin and its stretch value is high. Given Tables 4 and 5, the Odgen model has a difference of less than 0.05 or (5%), indicating that the outcomes are appropriate in this study, whereas the Neo Hookean model has a difference of more than 0.05 or (>5%).

Table 2: Stress-Stretch result of Leporine skin for 1st boundary condition and 2nd boundary condition (force parallel to x-axis).

Stress (MPa)	Stretch (1st boundary)				Stretch (2nd boundary)			
	Ogden		Neo-Hookean		Ogden		Neo-Hookean	
	AP	AP	DV	AP	DV	DV	AP	DV
0	1	1	1	1	1	1	1	1
0.15	1.63	1.45	2.18	2.18	1.41	1.40	1.72	1.72
0.30	1.78	1.55	3.67	3.67	1.54	1.49	2.71	2.71
0.45	1.88	1.61	5.26	5.26	1.63	1.55	3.76	3.76
0.60	1.97	1.66	6.98	6.98	1.69	1.60	4.93	4.93
0.75	2.03	1.69	8.55	8.55	1.74	1.63	6.06	6.06
0.90	2.08	1.73	10.11	10.11	1.79	1.66	7.16	7.16

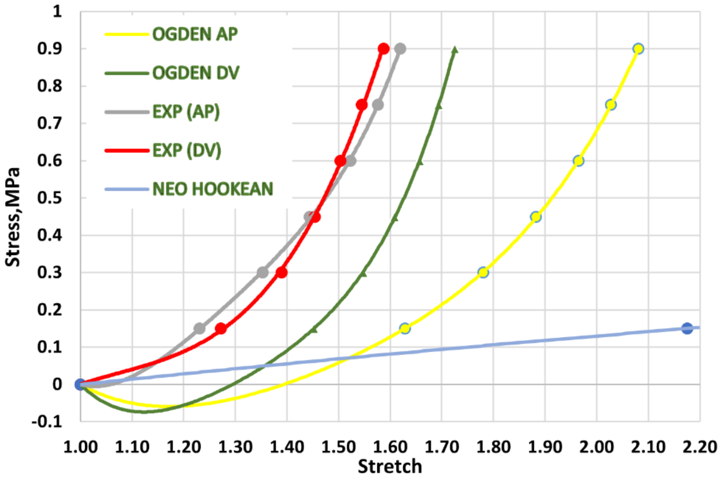

Figure 6: Stress-stretch curve of Leporine skin (1st Boundary Condition).

Table 3: Stress-Stretch result of leporine skin for 1st boundary condition and 2nd boundary condition (force parallel to the x-axis).

Skin category	Stretch at maximum force		Variance		Standard deviations	
	Ogden	Neo-Hookean	Ogden	Neo-Hookean	Ogden	Neo-Hookean
AP (1st BC)	2.19	12.13	0.0059	2.0858	0.077	1.444
AP (2nd BC)	1.87	8.53	0.0035	0.9628	0.059	0.981
DV (1st BC)	1.79	12.13	0.0025	2.0858	0.050	1.444
DV (2nd BC)	1.73	8.53	0.0021	0.9628	0.046	0.981

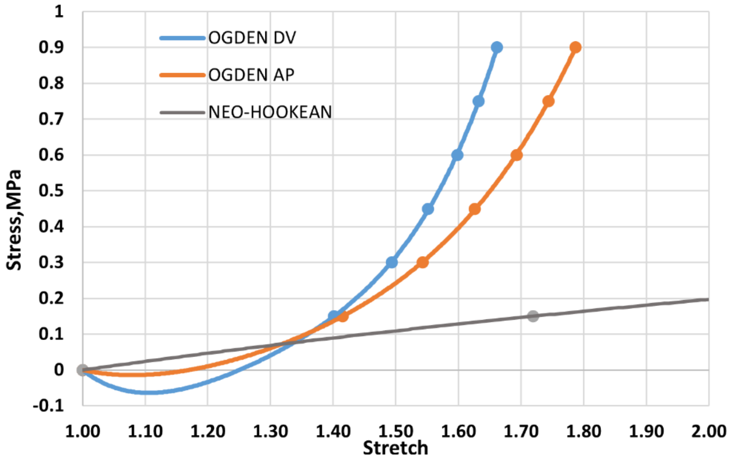

Figure 7: Stress-stretch curve of Leporine skin (2nd Boundary Condition).

The Odgen model, which curves more closely to the experiment curves conducted by earlier researchers, can be considered the best model for the computational study of leporine skin when compared to the Neo-

Hookean model (Manan et al., 2018). In both undeformed and deformed states with two different boundary conditions, Figures 8–10 display the displacement contour for both hyperelastic models. These results generally show that the Neo-Hookean model has a wider experimental gap than the Odgen model. In contrast to the experiment's elongation of only 68.658 to 138.365 percent, Odgen has the highest elongation, ranging from 63 to 108 percent, and Neo-Hookean has the most elongation, ranging from 118 to 900 percent. The variation in point direction between 0 and 30 degrees is most likely caused by the anisotropic conduct of leporine skin. To put it another way, leporine skin functions as anisotropic due to the nature of the fibres and collagens (Jor, 2011). The success of reproduction has also been used to support and provide examples for the assumption of indirect materials like leporine skin theories. In general, the Odgen model's conclusions are more accurate and comparable to trial results than the Neo-Hookean model, making it more suitable for computational studies of regular skin or delicate tissue.

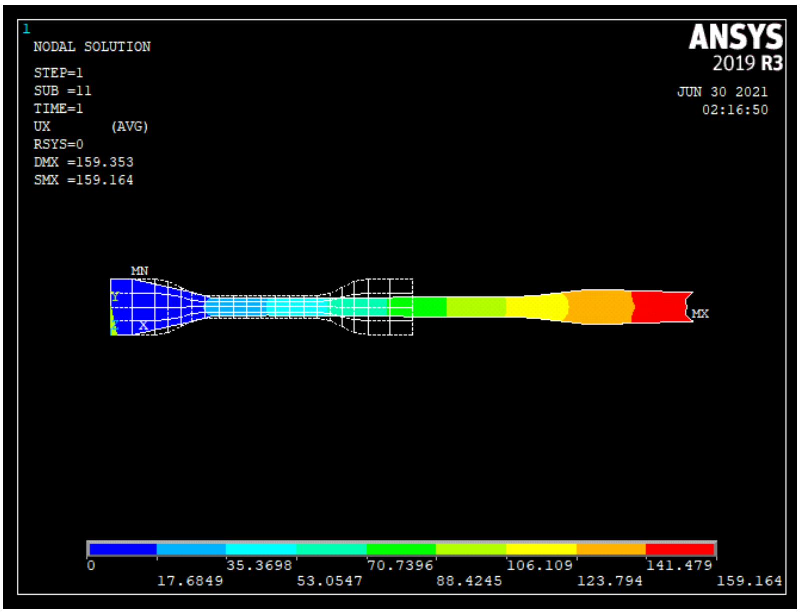

Figure 8: Stress-stretch curve of Leporine skin (2nd Boundary Condition).

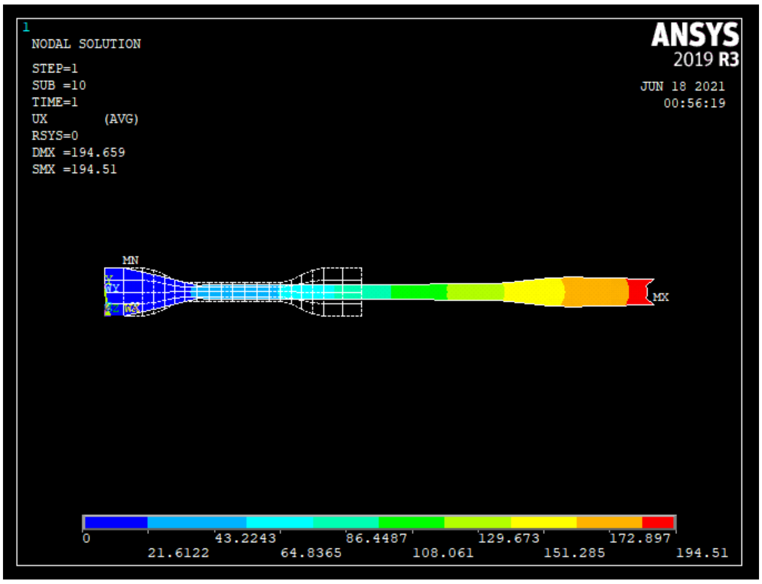

Figure 9: Simulated deformation and displacement contour for AP (Odgen model).

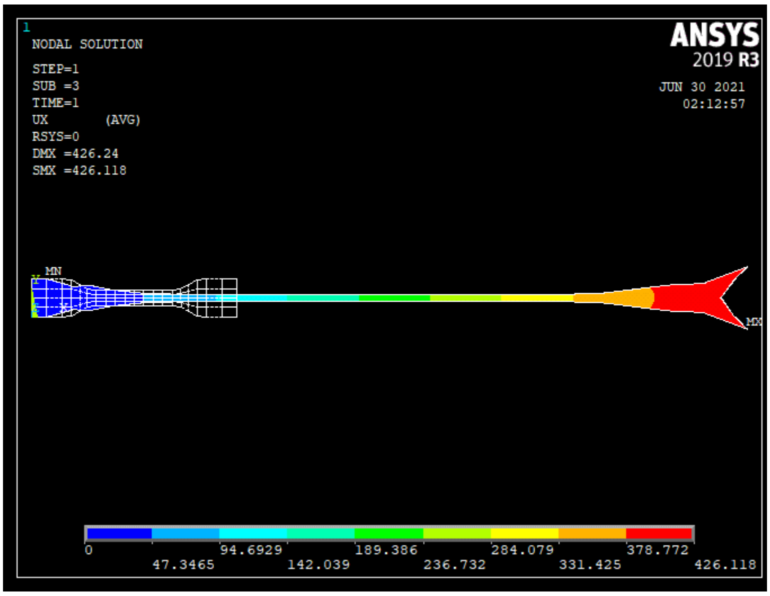

Figure 10: Simulated deformation and displacement contour for AP & DV (Neo Hookean model).

5 Conclusion

Leporine skin stretched more under a force with a 0 angle of orientation (parallel) than under a force with a 30 angle of orientation, according to the results of this study. The AP force vector exhibits more stretch than the Dorsal-Ventral force direction, according to the stress-stretch curves (DV). The Odgen model displays a smaller gap between the experiment parameters than the Neo-Hookean model. This outcome can later be used as a guideline or inspection again by a professional conducting a leporine skin study.

6 Availability of Data and Material

Data can be made available by contacting the corresponding author.

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