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Research paper

Characterisation of Skin Biomechanical Properties via Experiment-Numerical Integration

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Abstract

By having specific mechanical properties of skin, computational program and analysis become more reliable by showing the real skin behaviour. Up to date, mechanical properties of biological soft tissues (skin) haven't been accepted solely for official usage. Therefore, characterisation of the skin biomechanical properties might contribute a new knowledge to the engineering and medical sciences societies. This paper highlights the success in characterising the hyperelastic parameters of leporine (rabbit) skin via experimental-numerical integration. A set of five sample of leporine skin were stretched using the conventional tensile test machine to generate the load-displacement graphs. Based on the Ogden's constitutive equation and Mooney-Rivlin hyperelastic model, a stress-stretch equation was developed and a programme was written using Matlab. By varying the Ogden's and Mooney-Rivlin's parameters, the programme was capable of plotting stress-stretch and load-displacement graphs. The graphs that best match the experimental results will constitut to the corresponding coefficient, μ, and α for Ogden Model and C_1 and C_2 material parameter for Mooney-Rivlin Model that will best describe the behaviour of the leporine skin. The current results show that the Ogden's coefficient and exponent for the subject was estimated to be (μ = 0.048MPa, α = 7.073) & (μ = 0.020MPa, α = 9.249) for Anterior-Posterior (AP) and Dorsal-Ventral (DV) respectively for Ogden Model. Meanwhile the value for Mooney-Rivlin Model were estimated to be (C_1 = 1.271, C_2 = 1.868) & (C_1 = 1.128, C_2 = 1.537) for AP and DV respectively, which is in close agreement to results found by other researchers. Further analyses for comparison could be carried out by developing mathematical model based on other constitutive equation such as Arruda-Boyce and Neo-Hookean. Nevertheless, this study has contributed to the knowledge about skin behaviour and the results are useful for references.

Keywords: *Animal, Skin, Hyperelastic, Ogden, Mooney-Rivlin and Tensile.*

1. Introduction

Animal skin is an alternative specimen to be exploited instead of human skin. Several scholars agreed that pig or swine skin represents the closest and similar behaviour to human skin [1-3]. In addition, its topology, texture, architecture, metabolic rate, and drug permeability are similar to those of human skin [4]. Due to that reason, number of studies utilised the pig skin in their research especially in characterising the mechanical properties [5-11]. Nevertheless, other animal skin can also been quantified for their mechanical properties for example equine [12], leporine [13, 14], canine[15], bovine [16] and many more. Study on animal body or soft tissue is not only limited to research of veterinary in finding the remedies and medicine for animal itself but it is useful for science and technology especially in getting better solution for society or the world as general. Despite numbers of NGO and societies that refuse and are against experiments and testing on animal recently, yet it still has to be done on animal especially related diseases that are infected from animals itself such as Middle East Respiratory Syndrome Corona virus (MERS-CoV) from camels, Swine-Flu (H1N1) from pigs, Severe acute respiratory syndrome (SARS) from bird family, Japanese Encephalitis (JE) from mosquito and pig and many more. This diseases have killed thousands of people around the world hence the testing on animals will help in solving these problems.

Instead of testing on human and animal skin, the body organs were also tested for the same reasons. In general, the researchers have a similar aim which is to quantify the mechanical properties but using different specimen. For example, Chizari et al. [17] used the leporine flexor tendon to examine the mechanical properties of the graft structure. On the other hand, Cooney et al. [18] utilised the porcine linea alba to investigate the complication of laparoscopic surgery. From their study, they quantified the mechanical properties of linea alba in order to simulate the finite element model and quantify the effect of clamping and tissue dimension. In addition, Cooney et al. [18] highlighted that linea alba demonstrated a non-linear elastic and anisotropic behaviour. The same animal as studied by Cooney et al. was used, but Taylor et al. [19] studied the porcine muscle tissue fracture toughness (mechanical properties as well) instead of hyperelastic material properties. Moreover, rat supraspinatus muscle was studied by Miller et al. [20] to investigate the effect of preconditioning and stress relaxation on local collagen fibre re-alignment. Here Miller et al. [20] stresses that rat supraspinatus muscle behaviour is inhomogeous. In contrast, Luboz et al. [21] analysed the human soft tissue fat, muscle and buttock skin as samples for the study of ischial pressure ulcers that was a major public health in France. Not only that kind of soft tissues, but rabbit vocal fold [22], pig thoracics elastin [7], pig collagens [8] and many more animal soft tissues were utilised as specimens in numbers of research. Clearly, the soft tissues include skin for human or animal shows a complex behaviour as highly-non linear, anisotropic and inhomogeous [23-24]. All these characteristics of skin and soft tissue must be considered in further investigation or analysis of the behaviour and can be compared with other animal skin biomechanical properties. Hence, any related study on leporine skin or similar skin just can be simulate with computer anlysis instead sacrefices another life creatures. These shows the application by having the biomechanical properties. Therefore, the aim of this research is to characterise the leporine skin parameters accoring to Ogden and Mooney-Rivlin models.

2. Methodology

A combination of procedures which consists of an in-vitro experiment and a simple computational analysis are divided into several stages. This work was started with sample preparation of leporine skin which was followed by a mechanical testing for the experimental procedure and concluded by determining the desired properties using numerical approach. The flow chart in Fig. 1 illustrates the methodology.

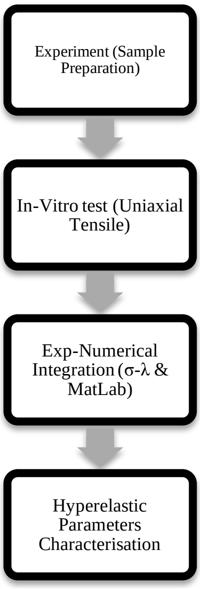

Fig. 1: The Flowchart of the project

2.1. Experimental- Material Preparation

The samples were prepared from a fresh slaughtered male leporine skin of the age of 24 month old as mentioned by breeder. The size and dimension are in accordance to International ASTM (D2209-00) for standard testing method for tensile strength of leather. Four samples of skin taken at the whole body. The overall dimension of dogbone shape skin prepared with 171mm of length and 31.8mm of width. To obtained the actual size during cutting the samples, firstly: actual drawing size printed on paper (schematic drawing) and mapped with plastic mould board to provide an accurate cutting shape as standard required. Then, the plastic mould with dogbone shape will help in cutting the leporine skin as much as accurate it can for the samples. The samples prepared were categorised into two direction and they are i) in direction of along the Anterior and Posterior of the body (AP) and ii) in direction of along the Dorsal and ventral of the body (DV).

2.2. In-Vitro- Mechanical Testing

Testing was performed using Instron Mechanical test machine (Instron, Dynatup 9250) from the Strength of Materials laboratory, Faculty of Mechanical Engineering UiTM Shah Alam, Selangor. Tensile testing performed using 240N load and speed 254 ± 50 mm/min. A wide jigs with knurling was used to clamped the samples at the both end of dog-bone Shape and tighten as much as it could because it quite slippery. Few samples were disposed due to slip-faulty during testing. It cannot be reuse because of the samples already stretched even it not reach the maximum load applied. During the testing, only the successful sample until the maximum loading applied were taken as absolute result. The mechanical properties were determined from tensile testing machine and the parameters obtained were tensile stress, elongation, strain and etc. By having these basic mechanical properties, the skin properties can be determined from formula of stretch-strain.

2.3. Numerical Integration- Matlab Programme Development

The experimental result were integrated with Matlab (ver. R2009) UiTM license programming to tabulate and synthesis the mechanical properties of skin obtained. The curve fitting between experimental and numerical result had shown the synchronisation of skin properties that is to be determined. As for comparison purposes, the obtained graphs between experiment result was compared with graphs generated by numerical integrating process (Matlab). Hence, all the graphs was plotted together for comparison process. As the material was considered to be hyperelastic in which it could be characterised by the strain energy function, *W*, the Ogden theory was employed as formulation for the subsequent numerical computation. R. Ogden [25] proposed the strain energy function, *W*

$$W = \sum_{i=1}^{N} \frac{\mu_i}{\alpha_i}\left(\lambda_1^{\alpha_i} + \lambda_2^{\alpha_i} + \lambda_3^{\alpha_i} - 3\right) \tag{1}$$

λ_i are the principal stretches; μ_i and α_i are the material parameters with the function's order of *N*. This assumption was used by Evan [26] in his research in the year 2009.
Considering the Ogden model Eq. 1, where the material is assumed to be isotropic, hyperelastic and incompressible [26], the relation of engineering stress, σ_E and principal stretches, λ, is described by

$$\sigma_E = \frac{\mu}{\lambda}\left(\lambda^{\alpha} - \lambda^{-\alpha/2}\right) \tag{2}$$

This equation has been used by Evans and Holt [27] to compare their results with others. A brief derivation of it is represented in Eq. 1 and Eq. 2. Before applying this approach to the current results, a parametric study designed to investigate the sensitivity of Eq. 2 to the variation in μ and α was investigated.
The second model was adopted from Mooney-Rivlin hyperelastic theory [28] and the stress-stretch equation are:

$$2C_1\left(\lambda - \frac{1}{\lambda^2}\right)\left(1 + \frac{C_2}{\lambda C_1}\right) \tag{3}$$

3. Results and Discussion

Two type mechanical properties were obtained in this study and they are, basic mechanical properties (Stress and strain) and biomechanical properties (the hyperelastic model parameters) from Ogden model and Mooney-Rivlin model.

3.1 Basic Mechanical Properties

The main objective for the leporine skin analysis is to investigate and compile more information on the small size animal as shown in Table 1. (the basic mechanical properties of Leporine skin). Handling this small size animal is considered easy in sample preparation, but data analysing process for leporine skin is quite challenging. Some difficulty was experienced due to uneven elongation and stress recorded. The thin skin of the leporine makes it easily rupture while undergoing tension operation. Fig.2 and Fig. 3 shows the acceptable range of standard deviation value.

Table 1: Mechanical properties of Leporine skin.

	AP	DV
Tensile Stress (MPa)	3.79	2.82
Std Dev	2.65	1.38
Variance	7.000	1.904
Strain (%)	71.05	76.51
Std Dev	0.201	0.134
Variance	0.040	0.018

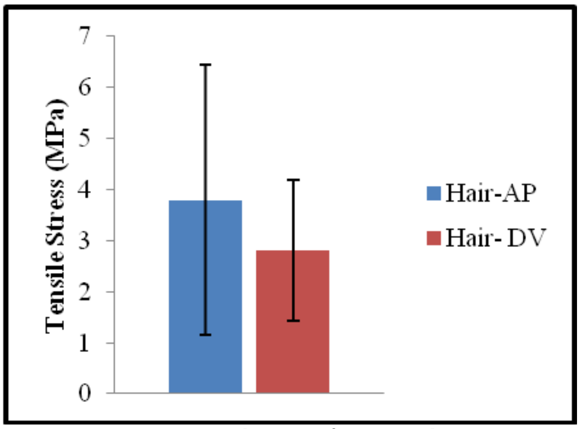

Fig. 2: Tensile stress of Leporine skin

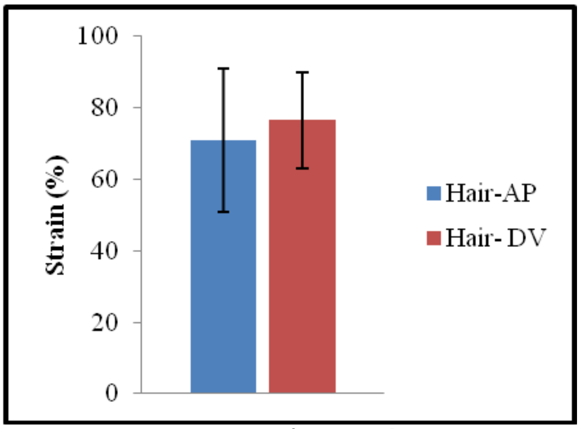

Fig. 3: Strain of Leporine skin

3.2 Biomechanical Properties

The stretch results and stress-stretch curve as in Table 2, Fig. 4 and Fig. 5 also shows a smooth and almost similar result and curve for AP and DV skin of leporine. Both results of AP and DV direction seem to have similar trend with different values of hyperelastic parameter due to anisotropic behavior of the results indicates that the leporine skin behave as anisotropic due to the arrangement of fibre and collagens as discussed by other researcher [8]. Furthermore, the vital features of statistical results also shows that variance of maximum tensile stress was slightly bigger (7%). This high dispersion of results and irregular finding might contribute to the unexpected results obtained. Another reason why this leporine result seems irregular might due to the uneven elongation as mentioned previously. The uneven elongation and uneven stress recorded could disturb the data that was being analysed, hence producing the unexpected results. In addition, Table 3 compiled the new finding of the leporine skin biomechanical properties for two models analysed between Ogden model and Mooney Rivlin respectively. As a supporting data and information, the leporine skin experimental data will be further analysed if any future finding could explain these unpredicted results. Nevertheless, leporine skin will only be treated as a supporting information only for future study.

Table 2: Stress-Stretch result of Leporine skin

Stress (MPa)	Stretch	
	AP	DV
0.00	1.000	1.000
0.15	1.231	1.272
0.30	1.353	1.390
0.45	1.444	1.454
0.60	1.523	1.504
0.75	1.576	1.545
0.90	1.619	1.587

Table 3: Biomechanical properties of Leporine skin

Hyperelastic Model	Parameters	Skin Categories	
		AP	DV
Ogden	μ	0.048	0.020
	α	7.073	9.249
Mooney-Rivlin	C_1	1.128	1.271
	C_2	1.537	1.868

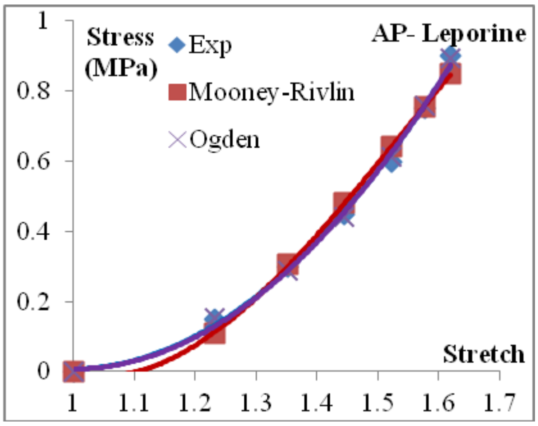

Fig. 4: Stress-stress curve of Leporine skin (AP direction)

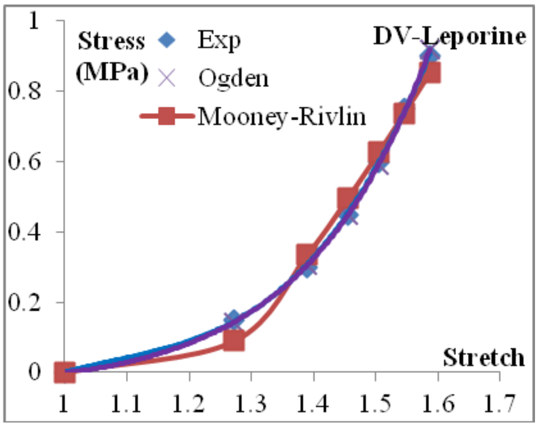

Fig. 5: Stress-stress curve of Leporine skin (DV direction)

4. Conclusion

As a conclusion, the main objective to characterise the biomechanical properties of leporine skin was successfully achieved. Table 3 illustrates the overall biomechanical properties. The characterisation of this animal skin parameter via integration of experimental-numerical shows an innovation technique and provides new data for skin analysis.

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