

Mechanical Behavior of the Skin: Men Versus Women, a Preliminary Analysis

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Abstract. In order to numerically simulate the contact between equipment and the skin, it is necessary to have equations that satisfactorily reproduce the mechanical behavior of the skin. Taking into account the variability of the mechanical behavior of the skin, it is desirable that the determination of the coefficients of these same equations and the limits of load application are based on experimental results. The mechanical behavior of the skin depends on the place where the contact occurs, the gender and age of the individual, among other factors, as well as the test parameters used, which makes it difficult to obtain these coefficients and limits. The objective of this study is to verify if it is possible to reproduce the mechanical behavior of the skin by performing the ANOVA approach of the experimental data and verify if the limits of load application in safety and comfort remain stable for a group of individuals. Indentation test that allows to obtain the force vs deformation curve in which the maximum reached is when the maximum pain is reached and where the instant where the pain threshold occurs (pain onset) is also recorded. The test was performed at a specific point on the forearm, with a spherical tip indenter, with a diameter of 5 mm, at a speed of 1 mm/s in eighty (80) healthy subjects, aged between 20 and 28 years, 40 women and 40 men.

Keywords: Wearable equipment · Compression test · Soft tissue deformation · Comfort · Statistical analysis · Gender · ANOVA

1 Introduction

Rehabilitation equipment has a high incidence of rejection/discontinuation (30% [1]). One solution to overcome this problem is to use simulation to develop rehabilitation equipment that fits the desired function, but it also takes into account end-user comfort [2]. To do this, it is essential to consider the contact between the user and the device. However, in order to digitally simulate the contact between the device and the skin, it is necessary to create an equation that sufficiently reproduces the mechanical behavior of the skin and to know the application limit of the load for the safety and comfort of the user [3]. Given the changes in the mechanical behavior of the skin, it is desirable to determine the coefficients

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of these same equations and limit the application of loads based on experimental results. The mechanical behavior of the skin depends, among other things, on the location of contact, the gender and age of the individual, and the test parameters used, making it difficult to obtain these coefficients and limits [4,5].

In this study it is investigated whether the mechanical behavior of the skin can be reproduced by performing ANOVA approach of experimental data, whether the results are consistent for the group of the selected individuals, and whether which are limits to the application of load in safety and comfort. The purpose of this study is as follows: discomfort is one of the main causes for discontinuation of rehabilitation equipment. The compressive forces generated at the interface between the person and the device cause discomfort. Mathematical models are needed to simulate skin contact, such orthosis [4]. Previously it is important to perform a preliminary analysis, to find which are the best explanatory variables to include in models.

In terms of motivation, proper design of portable equipment includes a focus on comfort, imitation of skin contact with the equipment. The preliminary analysis developed in next sections, previously to the proposal of new model, is a practical tool for comfort assessment. There are factors that may trigger or be related to discomfort/pain, namely gender, age, personality, family influence, cultural and hormonal factores [6].

A study presented in [7], based on the indentation method, performed "in vivo", was used as a new method to determine the mechanical properties of the skin. This method also makes possible to determine the properties of the skin surface volume. In addition, the authors of [7] used other mechanical models in order to analyze the effect of the subcutaneous layers during measurements, thus making it possible to know the elastic properties of the skin.

In the present work, the indendation test was performed on 40 women and 40 men, 80 healthy participants aged between $20 - 28$ years, at a speed of 1 mm/s using a spherical tip indenter with a diameter of 5 mm at a specific point on the forearm. This allows to obtain a force-to-deformation curve that records when the maximum pain is reached and when the pain threshold occurs (pain onset).

This article is divided in six sections. An introduction starts the manuscript; in Sect. 2 are presented some theoretical issues about analysis of variance; follows Sect. 3 with a brief description of the used methodology; in Sect. 4 is performed the empirical application; in Sects. 5 the results are detailed and discussed; by last the article ends with the conclusions.

2 Preliminaries

2.1 Analysis of Variance

Experimental Design One Factor. The purpose of these methods is to compare k treatments ($k \geq 2$) [8,9]. Imagine a random selection of k groups of individuals, each with size n_i, $i = 1, \ldots, k$. Each group i supported the treatment i, $i = 1, \ldots, k$. If each group has the same size, the design is considered as balanced. If only two independent random samples are studied ($k = 2$), t-tests are useful to compare the means of each group. The t-tests are adequate

to compare two independent samples, but when there exist $k > 2$ independent samples, it is usual to use the analysis of variance technique. The data of k samples is usually written as y_{ij}, with Y the value of the variable under study, for individual j in sample i, $j = 1, \ldots, n_i$, $i = 1, \ldots, k$. To compare simultaneously the means of k groups it is usual to compare simultaneously all groups, for example the parametric methods Scheffé [10] or Tukey are the most used. For a nonparametric approach we can use Jonckheere-Terpstra test [11,12] or even Kruskal Wallis test [13,14]. In [15] the author describes a wide number of nonparametric techniques.

Theoretical Model. Formal inference to compare means of different treatments implies the definition of probabilistic models. It is supposed that the variable under study Y_i associated to the $i-th$ treatment is Gaussian with mean μ_i and variance σ^2. If Y_{ij} is a random variable (rv) associated to the observed value y_{ij} the probabilistic model is given by (1)

$$Y_{ij} = \mu_i + \varepsilon_{ij}, \ (\ j = 1, \ldots, n_i, \ \ i = 1, \ldots, k), \tag{1}$$

with ε_{ij} rv's independents and Gaussian

$$\varepsilon_{ij} \cap N(0, \sigma^2). \tag{2}$$

The model can be rewritten as (3)

$$Y_{ij} = \mu + \alpha_i + \varepsilon_{ij}, \ (i = 1, \ldots, k, \ \ j = 1, \ldots, n_i). \tag{3}$$

We are able to obtain confidence intervals at $(1-\alpha) \times 100\%$ for each μ_i. Since $\widehat{\mu}_i = \overline{y}_i$ and from (1) and (2) we can conclude

$$\overline{y}_i \ \cap N(\mu_i, \sigma^2) \tag{4}$$

following

$$\frac{\overline{y}_i - \mu_i}{\sigma/\sqrt{n_i}} \cap N(0,1) \tag{5}$$

or, if σ is unknown,

$$\frac{\overline{y}_i - \mu_i}{S/\sqrt{n_i}} \cap t_{[N-k]}. \tag{6}$$

The confidence intervals (CI) considering a confidence level $(1-\alpha) \times 100\%$ for each μ_i are given by (7)

$$\overline{y}_i - t_{[N-k;1-\alpha/2]} \frac{s}{\sqrt{n_i}} \leq \mu_i \leq \overline{y}_i + t_{[N-k;1-\alpha/2]} \frac{s}{\sqrt{n_i}}. \tag{7}$$

To investigate whether the treatments have identical means or not can be tested the hypothesis (8) using as statistical test the formula (6)

$$H_0 : \mu_1 = \cdots = \mu_k \text{ versus } H_1 : \text{ some } \mu_i \text{ are not equal.} \tag{8}$$

A rejection of H_0 means that there is experiential evidence that treatments differ from each other. In terms of the effect of treatment α_i, the above hypothesis can be described as

$$H_0 : \alpha_1 = \cdots = \alpha_k \ = 0 \text{ versus } H_1 : \text{ some } \alpha_i \text{ are not null.} \tag{9}$$

To perform the test defined by (9) it is necessary to calculate the total variability of $\widehat{\mu}_i = \overline{y}_i$ around $\widehat{\mu} = \overline{y}$ given by the sum of squares of treatment deviations (16)

$$SS_{TREAT} = \sum_{i=1}^{k} n_i \left(\overline{y}_i - \overline{y}\right)^2. \tag{10}$$

A large SS_{TREAT} suggests that the treatments are distinct. It is necessary to take its average value, dividing by the degrees of freedom (11)

$$MS_{TREAT} = \frac{\sum_{i=1}^{k} n_i \left(\overline{y}_i - \overline{y}\right)^2}{k-1} \tag{11}$$

and compare with the variability of each observation within the sample, i.e., with the mean sum of squared errors defined as (12)

$$MSE = s^2 = \frac{\sum_{i=1}^{k} \sum_{j=1}^{n_i} \left(y_{ij} - \overline{y}_i\right)^2}{N-k} = \frac{SSE}{N-k}. \tag{12}$$

The F test statistic associated to test hypothesis (9) is given by (14)

$$F = \frac{\text{average sum of squares due to treatments}}{\text{mean sum of squares of residuals}} \tag{13}$$

$$= \frac{MS_{TREAT}}{MSE} \cap F(k-1, n-k). \tag{14}$$

The critical region of test (9), for significance level α is given by (15)

$$F_{|H_0} > F_{(k-1,n-k,1-\alpha)}. \tag{15}$$

The total variability SST (16) is measured by the squared mean of the deviations of each observation from the overall mean

$$SST = \sum_{i=1}^{k} \sum_{j=1}^{n_i} \left(y_{ij} - \overline{y}\right)^2 \tag{16}$$

and can be decomposed by the sum of two terms: the inter-group variability given by SS_{TREAT} and a variability within each group SSE, given by (17)

$$SST = SS_{TREAT} + SSE. \tag{17}$$

3 Methodology

To compute models that estimate the interaction of soft tissues and equipments it is essential to select the participants, collect their individual characteristics and ask them to perform the indentation test of compression/decompression. In Fig. 1 we can find all steps of the present work.

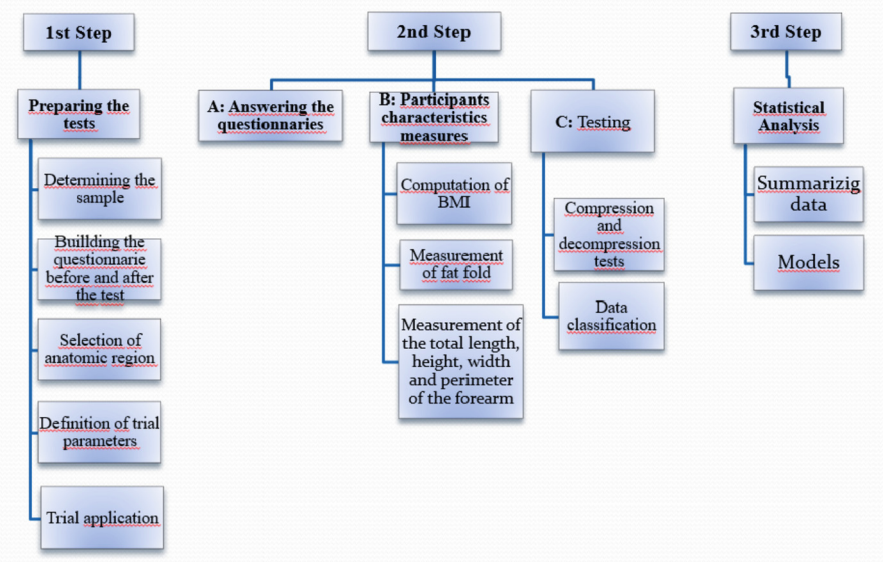

Fig. 1. Methodology summary.

4 Empirical Application

4.1 The Sample

In order to achieve the proposed objectives, indentation tests were performed at a specific point on the harm considering eighty healthy individuals, aged between 20 and 28 years, 40 women and 40 men. The individual physical characteristics can be found in Table 1.

The participants have body mass values between $40kg$ and $110kg$, heights between $1.44m$ and $1.88m$, fat folds between 1.05 mm and 10.7 mm and BMI between 15.56 Kg/m^2 and 34.30 Kg/m^2. The statistical tests of means comparison [8] led us to conclude that the mean and the respective standard deviation referring to the fat fold, body mass, height and BMI are distinct in the different genders. Establishing an analogy between genders, it can be seen that the average of female fat folds is higher than that of males. As for body mass and height, the female gender has lower values than the opposite gender, which leads to a lower BMI value. BMI presents higher levels (pvalue = 0.031) in the male gender compared to the female gender, revealed by the medians of the box-plots. As for the adipose fold, the opposite is verified, also by analyzing the medians (pvalue = 0.045). There is a single strange observation in the male gender, in both variables.

Table 1. Sample means and sample standard deviations corresponding to each measured variable, fat fold, body mass, height and BMI per gender (Males and Females).

	Female				Male			
	Adipose Fold [mm]	Weight [Kg]	Height [m]	BMI [Kg/m^2]	Adipose Fold [mm]	Weight [Kg]	Height [m]	BMI [Kg/m^2]
Sample mean	5,03	59,56	1,625	22,496	3,876	77,42	1,755	25,08
Standart Deviarion	2,872	10,89	0,070	3,572	2,51	12,29	0,057	3,402

4.2 Questionnaires

The implementation of questionnaires were carried out with the aim of analyzing and evaluating the psychological component and physical condition of the individual. Through the pre-questionnaire, parameters such as nervousness, a bad night's sleep, among others, which may or may not interfere with the indentation test to be performed, were evaluated. While the post-questionnaire aims to interpret the individual's feeling before the indentation test to which he was submitted, that is, how the individual himself evaluates the pain and discomfort he felt during it. The questions of interest are found in Table 2. The analysis of results will be performed with detail in a short future.

4.3 Experimental Methods

For the in vivo tests, a single anatomical region was selected, the anterior region of the forearm, due the objective of this study is focused on the feeling of pain associated with discomfort, being necessary to focus only on a single region to avoid disperse results. A precise point of this anatomical region was found, in order to always be the same point tested in all individuals. Initially, the measurement of the total length of the forearm (A1) was performed, and later the point (A2) used in the tests was calculated, which is located at 37% of the distal region of the fist, represented in Fig. 2 [16]. The selection of this region is due to the fact that it promotes less discomfort and has the particularity of being less painful for those undergoing the test. In addition, it is a region that is easily accessible to the indentation equipment and is a region that is less subject to the various natural movements of the body. In this way the working procedure becomes easier [17].

The test equipment used consists of a motor, an indenter and a load cell (see Fig. 3), which joins the motor to the indenter through a wire that allows the reception, by the same, of the applied force and of the felt deformation. It also has a metal platform where the individual will place the forearm. The operator can control various parameters from a portable computer.

Table 2. Per and Post questionnaires questions.

Pre - Questionnaire	Post - Questionnaire
1- Do you feel prepared for the test?	1- Did you feel un-comfortable during the test?
2- Did you sleep well tonight?	2- Did you quickly reach the sensation of pain?
3- How was your physical activity during yesterday?	3- Did you reach yours maximum permissible pain point?
4- Are you tired?	4- Do you have signs of injury?
5- Do you feel nervous?	5- Was it painful to perform the test?
6- Are you sportsman?	-------



Fig. 2. Selected anatomical point - Anterior region of the forearm. Adapted from [16].

Forces perpendicular to the lower limb surface are applied at a velocity of 1 mm/s [2] until unbearable pain[1] is perceived by the participant (see Fig. 4).

[1] Perception of Pain: "Unpleasant emotional and sensory experience associated with tissue damage" [18].

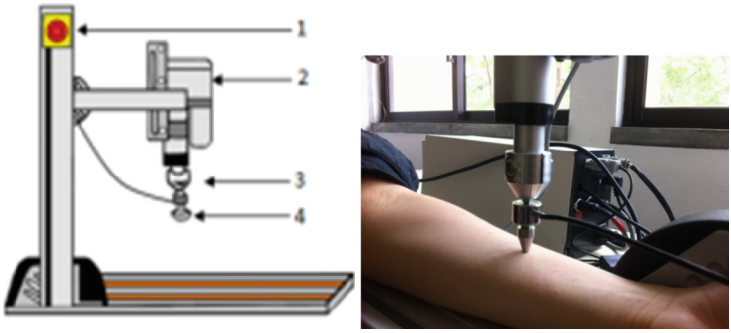

Fig. 3. Left - Equipment of test: Indentation machine 1 - emergency button; 2 - motor; 3 - load cell; 4 - indenter. Rigth - Example how a test is applied. The forearm is supported.

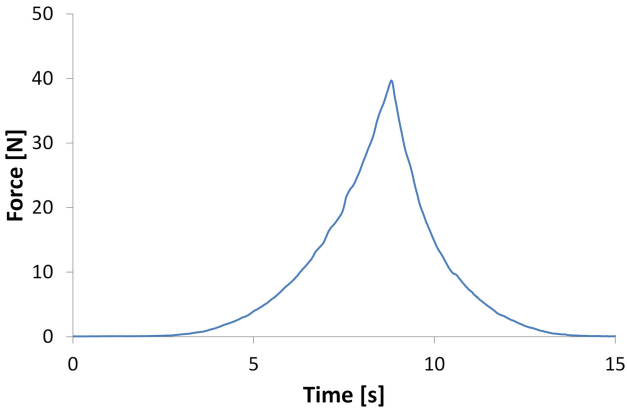

Fig. 4. Forces perpendicular to the upper limb surface are applied at a velocity of 1 mm/s until unbearable pain is perceived by the participant.

The spherical stainless steel indenter with a diameter of 5 mm was applied (see Fig 5). Maximum force and deformation are measured in the specific location (see Fig. 2) that corresponds to the particular point of contact between upper limb and orthosis AFO.

The force is measured by the soft tissues test equipment with a force transducer $(0-250N)$ placed in the indenter; a potentiometer transducer (0–50 mm) registers the deformation (see Fig. 3, on left).

The results are obtained at a sampling frequency of 40 Hz. The indenter is positioned perpendicularly to the anatomic test point, approaching the skin and starting the indentation at a constant speed. When the individual feels the maximum pain limit, a controller acts and the indenter turns to its initial position, at the same speed. Five trials are performed for each individual and between each trial there is a two-minute break. During the performance of the

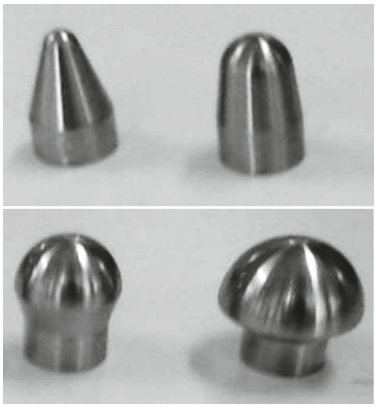

Fig. 5. Spherical stainless steel indenters with 5 mm, 10 mm, 15 mm and 20 mm of diameter. Used indenter: 5 mm of diameter (top left).

same, the value of the beginning of the discomfort is registered (force applied in Newton).

Each test consisted by the compression of the test point until the individual felt the maximum pain, allowing to register the maximum force F_{Max} and the deformation values δ. During the test, each individual verbalized the onset of pain, allowing to obtain deformation and strength for the pain threshold. Each participant performed five tests. A compression-decompression curve was obtained for each test. Notice that Fig. 6 presents two separate parts: the compression curve (top) and decompression curve (bottom). As we can see in Fig. 6, the xx-axis represents the deformation suffered by the soft tissues and the yy-axis the force applied during it, as well as the point referring to the change in mechanical behavior, that is, when the individual reaches the maximum pain, decompression begins. It should be noted that during the compression period the force values obtained are higher than those recorded during decompression, for the same deformation.

5 Results

Summarizing some details about participants, BMI presents higher levels (pvalue = 0.031) in the male gender compared to the female gender, revealed by the medians of the box-plots (see Fig. 7). As for the adipose fold, the opposite is verified, also by analyzing the medians (pvalue = 0.045). There is a single strange observation in the male gender, in both variables.

Force and displacement values for pain threshold and maximum supported pain were recorded. The maximum load limit applied is always the biggest pain and indicates the risk of injury. The pain threshold is the recommended load to keep the device comfortable. These data were statistically processed in two different groups as female and male. The results will be published in a future

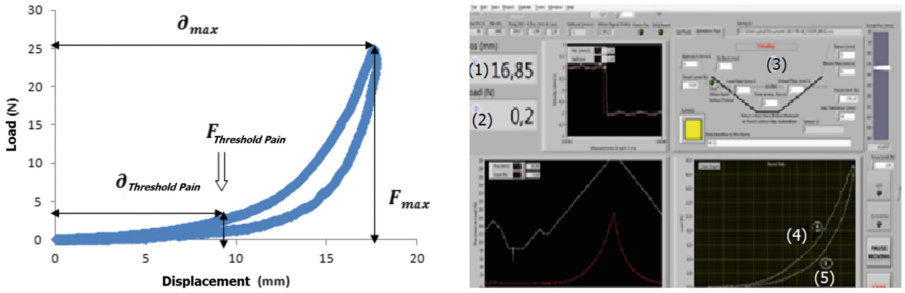

Fig. 6. Left: Representation of typical compression and decompression curves. Right: (1) Value of deformation; (2) Value of cargo;(3) Region where the test is performed, maximum force and rate of indentation; (4) Compression curve; (5) decompression curve.

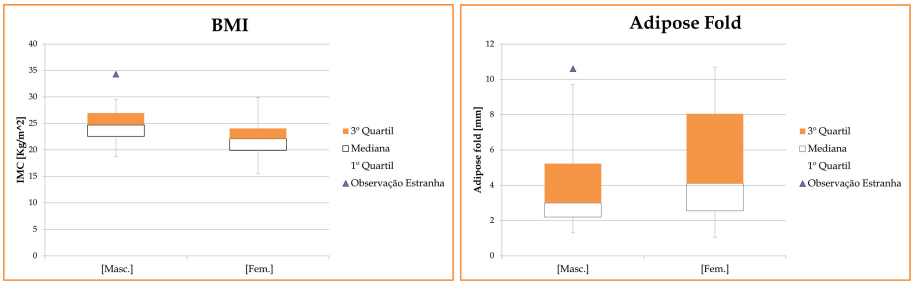

Fig. 7. Left -Box plot for BMI data (male versus women). Rigth - Box plot adipose fold data (male versus women).

article and will present the details of the results, but it can be shown shortly that both the maximum intensity and intensity at pain threshold were generally higher in the male group and also had more variance... 1st and 3rd quartiles are also higher in the male group than in the female group. However, the ratio of the force applied at the pain threshold (maximum pain) is less dispersed in the male group.

Figure 8 left shows the box-plot diagram related to strength for the two groups. These diagrams provide us with a summary of data location and dispersion measures (mean, median, 1st and 3rd quartiles, maximum, minimum, inter-quartile range and extreme observations). The maximum strength and the strength at the pain threshold are, in general, higher in the male group and also present a higher dispersion. In the male group, the dimensions of the 1st and 3rd quartile are also higher in male group than in the female group. However, the ratio between applied force at the pain threshold (maximum pain) has a smaller dispersion for the male group.

Figure 8 right shows the box-plot diagram related to the deformation for the two groups. The maximum deformation and also the deformation in the pain threshold are higher in the male group, and they also present a lower disper-

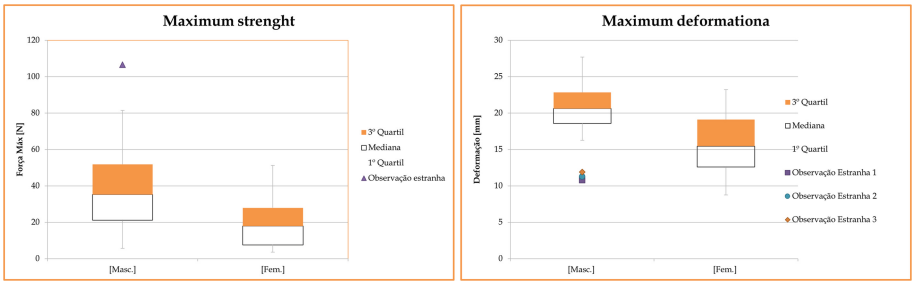

Fig. 8. Left: Box plot for maximum strength data (male versus women). Right: Box plot for maximum deformation data (male versus women).

sion. In the male group, the dimensions of the 1st and 3rd quartile are also lower than in the female group. However, the ratio between deformation in the pain threshold/maximum pain presents a similar dispersion for the two groups. Statistically we can conclude that maximum force presents differences between men and women (pvalue = 0.005), as well as, the variable maximum deformation (pvalue = 0.0035). Both medians, referring to the male gender, as well as the maximum and minimum values, non-discrepant, of the sample are higher compared to the female gender. A greater number of strange observations were detected, at maximum deformation, again in men group.

To identify some relations between individual characteristics and the variables determined during the trials, it was determined the speramann correlation coefficient. The results are summarized in Table 3.

Table 3. Spearman coefficiente between variables.

	GENDER			
	Male		**Female**	
	Adipose Fold	BMI	Adipose Fold	BMI
∂max	-0,103828071	0,228356	-0,024907025	0,272174
Fmax	-0,234153468	-0,05466	0,037853989	0,109998
∂Desconf.	-0,003080148	0,185092	-0,003080148	0,167133
Fdesconf.	-0,089539939	0,010996	-0,114401499	0,029848
Absorved Energy	-0,103828071	0,228356	-0,024907025	0,272174

Between men and women, there is a weak association between the variables under study with BMI and the fat fold, the Spearman correlation coefficient values in Table 3 are not statistically related, (pvalue>0.10).

Finally, using an ANOVA approach in an attempt to associate the studied variables, the F test (see expression 9), for significance level α given by (15) provided a $p - value = 0.003$. This means that men and women have distinct performances. All diagnostic tests, residual analysis and comparison tests under the aim of ANOVA analysis will be described in the extended version of this article.

6 Conclusions

In order to verify if it is possible to reproduce the mechanical behavior of the skin, were performed forearm point indentation tests in 80 participants. In the present manuscript was done a preliminary statistical analysis of the data. Considering the maximum strength, the male gender supports higher strength values and consequently has a higher maximum deformation value in its soft tissues, as well as a higher value of absorbed energy, compared to the female gender. Regarding BMI and adipose fold, although the male gender has a higher BMI than the female, it does not mean that it has a greater adipose fold. Probably it happens because the distribution of fat mass in both genders is different. It was applied the ANOVA technique, the global test F was significant (see expression 9), it is concluded that there are significant differences between men and women in terms of mechanical behavior of the skin. The assessment of psychological behavior and physical condition, through the questionnaires, the male gender practices more physical activity, is more tired and before the test he classified it as more painful compared to the opposite gender but a detailed analysis will be presented later. As future work, to reproduce the mechanical behavior of the skin is still needed an extended effort to characterize both the soft tissues properties and the level of tolerance for applied pressure, deformation and force and hence the ability to design for comfort. We intend to extend the models proposed in [19], taking other explanatory variables just as BMI, adipose fold measure, others and using generally linear models, e.g. logit regression.

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