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Research Article

Comparison of the Stress Analysis To Obtain The Tensile Properties of Three Type-1 and Type-3 Collagen Membranes

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Abstract

The aim of this study is to evaluate the mechanical tensile strength for control and specification of three collagen membranes, cross-linked and non-cross-linked, as well as their stress–strain curve.

The treatment of sequelae caused by destruction of the periodontal structure resulting from periodontal disease, especially the treatment of alveolar bone defects, known as guided bone regeneration (GBR), is generally aimed at restoring the periodontal insertion apparatus, with the possibility of structural support of membranes and/or barrier, and has been widely studied. Depending on the reaction to their biological environment, membranes can be grouped into two types: resorbable membranes, which, due to biological degradation, induce a tissue response that can negatively affect wound healing and complicate regeneration; and non-resorbable membranes, which have proven to be effective in preventing the invasion of connective and epithelial tissue in the healing area. Resorbable membranes have a high potential for

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application in periodontal and peri implant regeneration, which indicates collagen as the main extracellular component involved in processes, including cell migration and differentiation. Descriptive statistics of quantitative variables were made by calculating the mean, standard deviation, and standard error; the number of observations was also considered. Statistical inference was applied based on one-way analysis of variance (ANOVA) in the comparison of means in three types of membranes (Bioguide, Jason, and Lumina Dermal) for four dependent variables: elastic modulus (GPa), maximum load (N), breaking stress (MPa), and breaking strain (%). The mechanical characteristics of collagen membranes can be influenced by the action of glutaraldehyde, creating a cross-linking structure in the collagen matrix, thereby substantially increasing the mechanical properties of the membrane; on the other hand, this also increases cytotoxicity. Otherwise, the search for natural collagen membranes with good fixation properties is difficult, due to membrane standardization. Nonetheless, through dimensional and mechanical measurements, it is possible to mechanically qualify collagen membranes and compare them.

When assessing the physical stress and tensile properties of the three membranes, high levels of mechanical strength were observed, especially in the Lumina Dermal membrane by Criteria Biomateriais, which presents higher rates based on the methodologies and tests applied, mainly when compared to other samples.

Keywords: Collagen membrane; Tensile Strength; Stress

Introduction

The treatment of sequelae caused by destruction of the periodontal structure resulting from periodontal disease, especially the treatment of alveolar bone defects, known as guided bone regeneration (GBR), is generally aimed at restoring the periodontal insertion apparatus, with the possibility of structural support of membranes and/or barrier, and has been widely studied, according to Raz et al., 2019. Depending on the reaction to their biological environment, membranes can be grouped into two types: resorbable membranes, which, due to biological degradation, induce a tissue response that can negatively affect wound healing and complicate regeneration; and non-resorbable membranes, which have proven to be effective in preventing the invasion of connective and epithelial tissue in the healing area, according to the analysis by Bouguezzi et al., 2020. Resorbable membranes have great potential for application in periodontal and peri-implant regeneration. Studies proposed by Chu et al., 2016. indicate collagen as the principal extracellular component involved in processes, including cell migration and differentiation. Collagen membranes have many specific characteristics. However, the possibility of mechanical support — acting as a framework and aiding in tissue reconstruction — is essential, considering that the physical properties of these materials are similar to those of the tissue being replaced, in addition to being biologically acceptable (taking vascular applications into account) in the chosen tissues, as well as the elastic properties that allow expansion and contraction of the blood vessel while promoting the growth of the endothelium in these collagenous matrices, which are generally stabilized, and the processing to maintain stability during the time they remain in the proposed surgical bed, according to studies by Charulatha & Rajaram conducted in 2003. There has been growing emphasis on the use of resorbable membranes that are biocompatible with the host and do not require surgical reintervention for removal. Different types of guided tissue regeneration (GTR) barriers are available, in which various materials are used for manufacture, primarily bovine collagen types I and III, due to the presence of biocompatible components and the possibility of new fixation of the connective tissue and new alveolar bone formation, depending on the guided tissue regeneration technique used, according to studies by Martins et al., 2021. The application of collagen matrices in various physical forms is used in the augmentation of soft tissue, blood vessel and valve prostheses, and dressings, as well as in the treatment of skin defects and regeneration of bone tissue. However, these matrices — in addition to providing low mechanical support — act as a framework to help reconstruct the damaged tissue, which makes it essential that the physical properties of these materials are similar to those of the tissue being replaced, in addition to being biologically acceptable, such as (for example) in vascular applications, i.e., the material chosen must have properties to allow the expansion and contraction of the blood vessel and, at the same time, promote the growth of specific biological structures and regeneration (Charulatha & Rajaram, 2003). The possibility of new techniques for manipulating collagen with different substances, aimed at producing membranes that are highly resistant to reabsorption in vivo and thereby leading to the development of new structures (observed mainly in studies of several biomodels, including in humans) have shown biocompatibility and permanence in tissues, even after several months, resulting in significant guided tissue/bone regeneration, which was evidenced in the analyses by Vehashinayim in 2004. Collagen membranes are predominantly reabsorbed by enzymatic activity (protease and collagenase), but in order to reduce reabsorption, several physical and chemical cross-linking techniques have been used. However, their impact on the physical–chemical properties of the membrane is still unknown, according to the study by Schwarz and collaborators in 2006. On the other hand, Park and collaborators in 2015 stated that the cross-linking process presented low levels of toxicity, showing potential application in bone regeneration, since it was possible — through histological analysis — to observe degradation in a period of time greater than eight weeks, allowing satisfactory interaction in the integration of the vascularization process at the studied sites.

In a review carried out by Elangovan in 2018, a slightly higher level of advantages in the use of non-cross-linked membranes in relation to cross-linked ones was found, which can be explained by the long-lasting nature and increased incidence of tissue perforations reported. However, this increase was not statistically significant, mainly due to the use of these membranes in stabilizing bone graft materials at the site, thus increasing the entry of progenitor cells into the graft site, demonstrating a positive impact on vertical and horizontal bone gain, respectively. In studies conducted by Chandra et al. (2019) using 17 mice, evaluating perforations of the maxillary sinus membrane on the left and right side compared to cross-linked collagen membranes, non-cross-linked collagen membranes were shown to be more beneficial in terms of repair, with the use of a noncross- linked collagen membrane having demonstrated better results in a maxillary sinus with a perforated sinus membrane.

Occasionally, the search for an ideal membrane for guided tissue and bone regeneration takes into account the mechanical and physical properties considered in order to avoid tissue collapse, thereby facilitating its handling and placement. Such factors have been observed due to recent advances in the development of the combination of natural and synthetic polymers with or without biological substances and mediators, taking into account a graduated structure, based on the principle that the properties of the different layers of this biomaterial can be adapted in such a way as to design a membrane that retains its structural, dimensional, and mechanical integrity for long enough to improve periodontal regeneration, in the analysis carried out by Bottino & Thomas in 2015.

However, Elgali and collaborators stated in 2017 that most of these methods result in membranes with less efficacy for clinical application, mainly due to their high density and greater difficulty in handling, as well as a non-standardized and non-uniform degradation rate.

Purpose

Evaluate the mechanical tensile strength for control and specification of three collagen membranes, cross-linked and non-cross-linked, as well as their stress–strain curve.

Materials and Methods

Sample identification

The sample was sent to and analyzed at the AFINKO laboratory in São Carlos-SP, Brazil, filed under record number AFK223047, as shown in Table 1 and Figure 1:

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AFK235443	Lumina Dermal - Critéria Biomateriais
AFK235440	Bioguide - Geistlich Pharma
AFK235437	Jason - Straumann

Table 1: Identification and record of collagen membrane samples

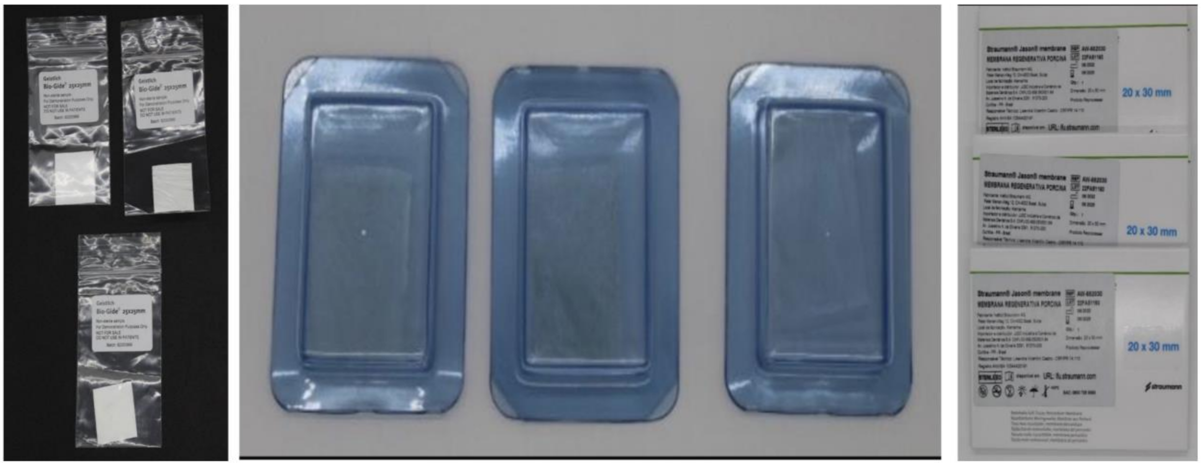

Figure 1,2,3: ***Figure 1:*** Sample of the Lumina Dermal - Criteria Biomateriais membrane, for laboratory analysis. ***Figure 2:*** Sample of the Bioguide - Geistlich Pharma membrane, for the laboratory analysis. ***Figure 3:*** Sample of the Jason - Straumann membrane, for laboratory analysis.

Purpose

Perform tensile test on the collagen membrane and characterize it.

Tensile Test

This test is used to acquire tensile property data for material control and specification, as well as for qualitative characterization and for the purposes of research and development. Tensile properties are rather susceptible to sample preparation and testing conditions, such as speed, temperature and humidity in some cases; the results are shown in Table 2.

Membrane	Quantity	Width	Thickness	Load	Speed
Lumina Dermal	3	19.03 ± 0.44mm	0.22 ± 0.04mm	500 N	5mm/min
Bioguide	3	25.23 ± 0.42mm	0.52 ± 0.12mm	500 N	5mm/min
Jason	3	20.27 ±0.29mm	0.15 ± 0.02mm	500 N	5mm/min

Table 2: Tensile test conditions at 23.8 °C with 46% humidity and 12 mm distance from the grips.

Before conducting the test, the specimens were immersed in distilled water for approximately 1 minute. After this period, excess water was removed from the surface with a paper towel and the membrane was tested immediately.

Results

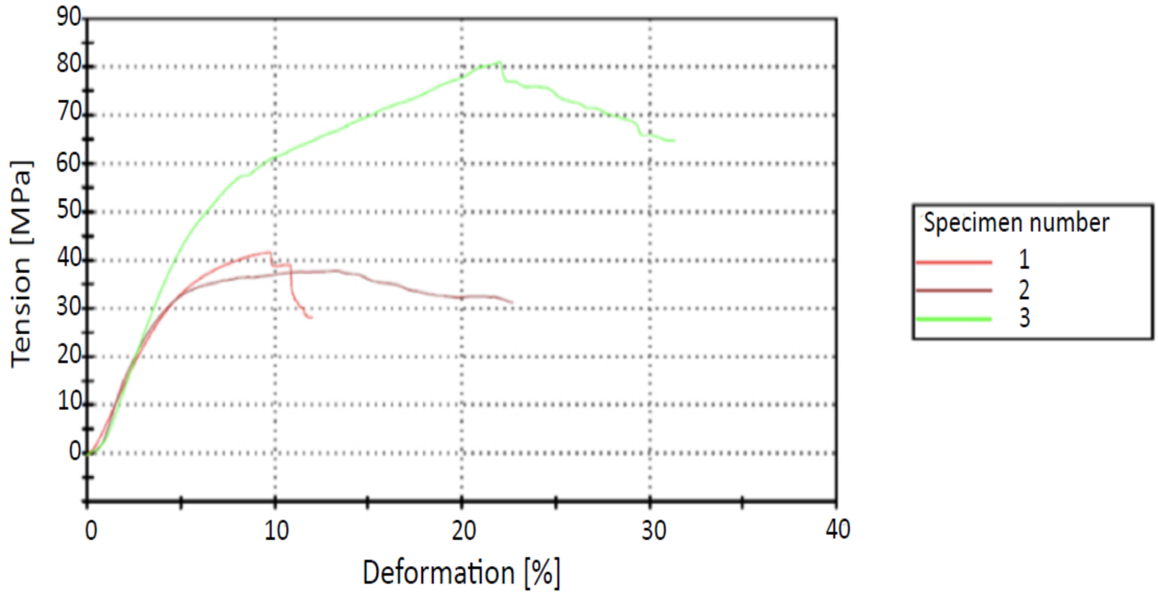

Figure 4: Stress–strain curve of the Lumina Dermal collagen membrane.

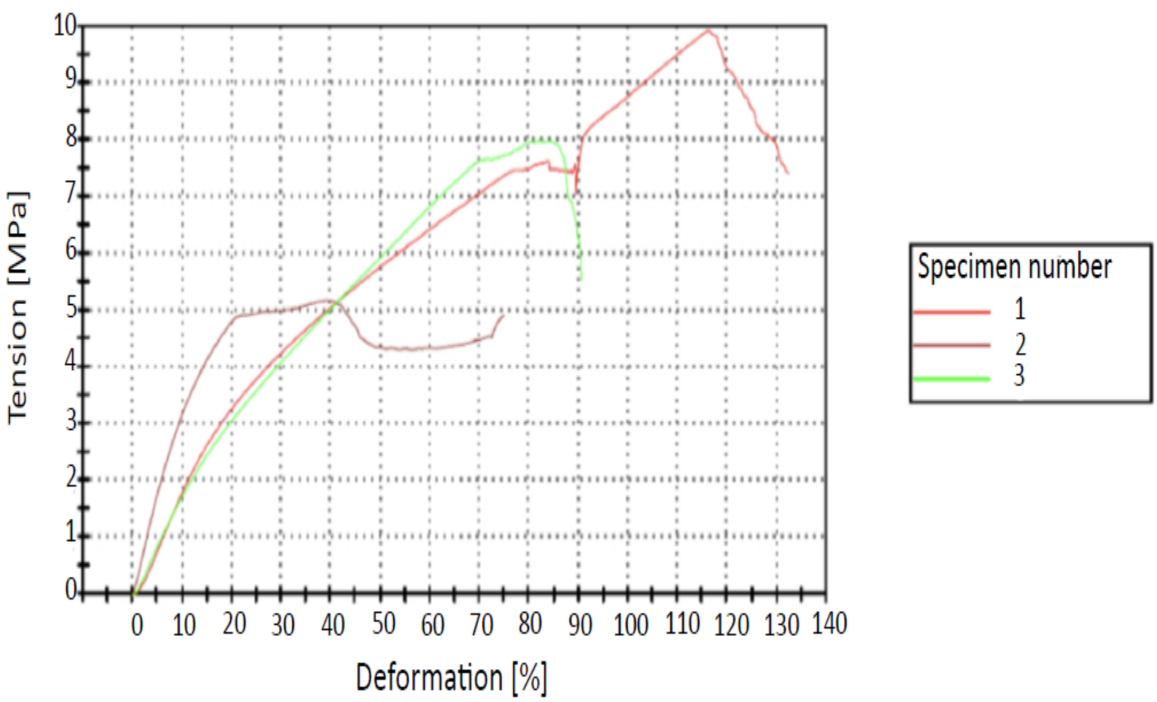

Figure 5: Stress–strain curve of Bioguide - Geistlich Pharma collagen membrane.

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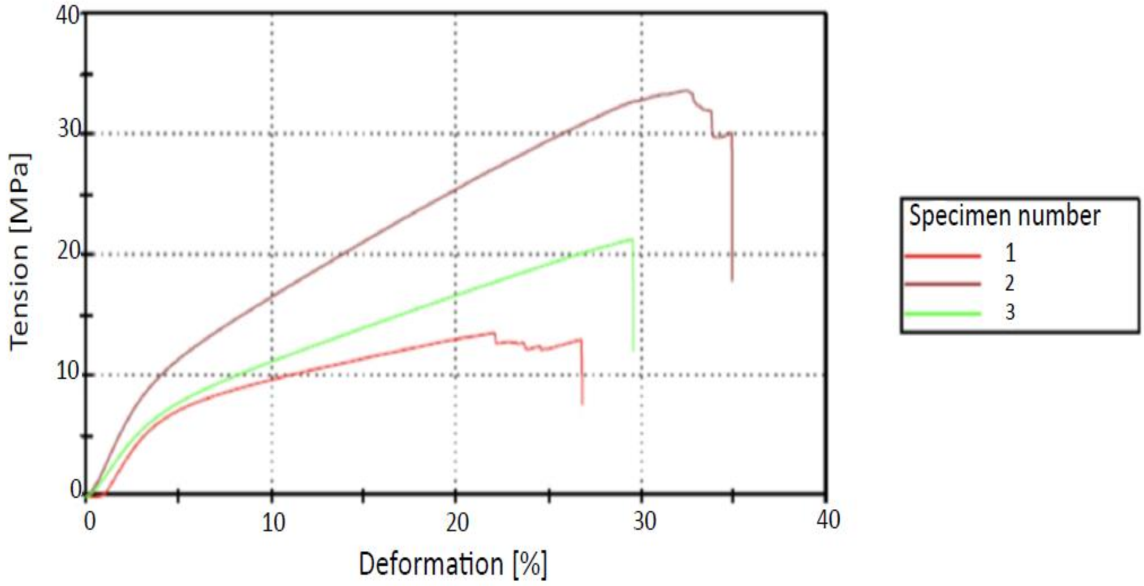

Figure 6: Stress–strain curve of the Jason - Straumann collagen membrane.

Membrane	Sample	Elastic modulus (GPa)	Breaking stress (MPa)	Breaking strain	Maximum load (N)
	1	0.39	41.76	9.78	234.92
Lumina Dermal	2	0.21	37.78	13.54	132.03
	3	0.30	80.96	21.95	285.81
	1	0.02	9.83	117.49	106.27
Bioguide	2	0.04	4.90	74.77	61.82
	3	0.02	7.96	84.72	136.50
	1	0.19	13.54	22.07	35.09
Jason	2	0.22	33.64	32.46	116.05
	3	0.16	21.27	29.52	67.18

Table 3: Results of the collagen membrane tensile test (mean and standard deviation).

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Membrane	Quantity	Elastic modulus (GPa)	Breaking stress (MPa)	Breaking strain (%)	Maximum load (N)
Lumina Dermal	3	0.30 ± 0.09	53.50 ± 23.87	15.09 ± 6.23	217.58 ± 63.34
Bioguide	3	0.02 ± 0.01	7.57 ± 2.49	92.33 ± 22.35	101.53 ± 37.57
Jason	3	0.19 ± 0.03	22.82 ± 10.14	28.01 ± 5.35	73.04 ± 40.40

Table 4: Summary of the results obtained after the collagen membrane tensile test.

Statistical Analysis

Descriptive statistics of quantitative variables were made by calculating the mean, standard deviation, and standard error; the number of observations was also considered.

Statistical inference was applied based on one-way analysis of variance (ANOVA) in the comparison of means in three types of membranes (Bioguide, Jason, and Lumina Dermal) for four dependent variables: elastic modulus (GPa), maximum load (N), breaking stress (MPa), and breaking strain (%). Assumptions regarding ANOVA were checked via normality test, variance homogeneity test, residual analysis, and statistical graphs. Posthoc mean comparisons were calculated via Tukey's test. All analyses were carried out at a 5% statistical significance level, via two-tailed tests and using open-source software jamovi [1] and R[2-3].

Discussion

Many different collagen membranes are available for clinicians with many different origins as porcine dermis, bovine tendon, equine tendon, and porcine pericardium for example (Adel Bouguezzi, Aymen Debibi , Abdellatif Chokri, Sameh Sioud, Hajer Hentati, Jemil Selmi). In the present study three different origin collagen membranes was compared, to evaluate the necessary tension to deform and tear - one from porcine pericardium, one from porcine dermis and one from bovine bone periosteum.

Material failure under tensile load is very rare in the actual working conditions of the materials. Failure of these collagen membranes can reasonably occur because of tearing during placement by the dentist or as a result of further loading conditions. There is no way to infer the tearing behaviour of a sample starting from the analysis of a tensile test. Tear tests give a better comparison among different materials as they provide information on the energy or force required to propagate a tear through the material (Emanuela Ortolani, Fabrizio Quadrini, Denise Bellisario et al.). The mechanics

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characteristics of the collagen membranes can be influenced by the

action of Glutaraldehyde, creating a cross linking structure in the collagen matrix, increasing substantially the mechanical properties of the membrane, on the other hand it increase the cytotoxicity (Charulatha*, A. Rajaram). Otherwise the search for natural collagen membranes with good properties for fixation is difficult due to standardization of the membrane. Nevertheless, through dimensional and mechanical measures it is possible to mechanically qualify collagen membranes, and compare them (ortolani et al). According to Roeder et al the collagen membranes have a characteristic stressstain curve divided in three distinct regions: "toe", linear, and failure. The failure stress become before the failure strain. The maximum load applied in each membrane in the present study describes the failure stress while the stain tension refers to the failure strain.

All the parameters were recorded to each membrane study, and the average results was compared. The parameters used to compare the three membranes (Jason, Bio-gide and Lumina dermal) was the maximum load, elastic modulus, tear deformation, and deformation tension, all of them applied in dry conditions, due to degradation of bio-gide in wet condition as described by Coíc et al. Lumina dermal exhibited the highest result for deformation tension, elastic modulus, and maximum load, followed by Jason in elastic modulus, and tear tension. Bio-gide exhibited the greatest value in tear deformation, followed by Jason. The maximum load obtained was in the lumina dermal samples, followed by Bio-gide. While Lumina Dermal is a new membrane, there is no comparison among the three membranes in the literature, the results found in the test were in accordance to Ortolani et al, though. These authors found that Bio-gide presented higher maximum tensile strain and tear load when compared with Jason, and maximum tensile stress and elastic modulus found in Jason. In dry conditions lumina dermal reached greater results when compared with Bio-gide except the deformation in which Bio-gide was significantly higher, similar result described by Coíc et al when compare Bio-gide with other membrane. Charulatha, A. Rajaram have compared one natural collagen membrane with some different cross-linked ones and found that the Glutaraldehyde treated membranes have almost three times more resistance strength. In the present study the lumina dermal has similar result reaching significantly statistical result in the stain tension supported without the cross-linking treatment, though.

Conclusion

When assessing the physical stress and tensile properties of the three membranes, one can see high levels of mechanical strength, mainly in the Lumina Dermal membrane manufactured by Criteria Biomateriais, which presents higher rates based on the methodologies and tests applied, mainly when compared to other samples.

Acknowledgments

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Conflicts of Interest

The authors declare no conflict of interest associated with this study.

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