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Mechanical Properties of Polyvinyl Alcohol/Collagen Hydrogel

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Abstract. The effects of the polyvinyl alcohol (PVA) concentration on mechanical properties of hydrogels based on blends of native or denatured collagen / PVA were examined. Blends of PVA with collagen were obtained by mixing the solutions in different ratios, using glycerol as a plasticizer. The solutions were cast on polystyrene plates and the solvent was allowed to evaporate at room temperature. Uniaxial tensile tests were performed in order to obtain the initial stiffness (up to deformation 0.1), the ultimate tensile stress and the deformation at failure of the material in the water-saturated hydrogel form. It was found that the material was elastic and the addition of PVA helped to enhance both the ultimate tensile stress and stiffness of the films. Samples prepared form denaturated collagen showed the higher ultimate tensile stress and the deformation at failure in comparison with those prepared from native collagen. The results suggest that we could expect successful application of the collagen-PVA biomaterial for tissue engineering.

Introduction

Over the past few decades, tissue engineering has been focused on development of biological substitutes to restore, maintain, or improve tissue functions. Collagen (Coll) is the most abundant biological material used for tissue engineering. It is the basic constituent of skin, bones, ligaments and connective tissues. However, tissue engineered collagen products have often inadequate mechanical properties in comparison with natural tissues [1]. A possible means to circumvent the problem is to associate the useful properties of natural and synthetic polymers through blending. Polymer blending is a technique largely applied in polymer science to obtain materials whose physical properties depend on the blend composition and may be modulated through compositional changes [2]. A group of materials termed 'bioartificial polymeric materials' have been produced by Giusti and colleagues [3]. These are based on different water-soluble polymers such as polyvinyl alcohol (PVA) or polyacrylic acid (PAA), combined with natural polymers like collagen, hyaluronan (HA) or gelatin. The blends can be cast as films, hydrogels or sponges according to requirements [4]. Polyvinyl alcohol (PVA) was chosen in this study because it is mechanically stable, flexible, inherently non-toxic, non-carcinogenic and elastic [5]. In our study, the effects of the polyvinyl alcohol (PVA) concentration on mechanical properties of hydrogels based on blends of native or denatured collagen / PVA were examined.

Material and Methods

Sample preparation. Blends of PVA with collagen were obtained by mixing the solutions in different ratios (PVA/Coll = 0; 0.3; 1; 2 and 3), using glycerol as a plasticiser. 6 % (w/w) solution of denatured collagen was prepared by dissolution of a frozen collagen suspension (VUP Brno, Czech Republic) by mechanical disintegration with a propeller in 5 % (w/v) acetic acid solution at 80 ºC. 5 % (w/w) solution of native collagen was prepared at temperature up to 40 ºC by a gentle mechanical disintegration with propeller in distilled water. 7 % (w/w) PVAMW 13000 (Sigma-Aldrich, USA) solution in distilled water was prepared by heating to the boiling point. The collagen, PVA solutions and glycerol were mixed in different ratios. Finally, pH of all the solutions was adjusted to 5.5. The solutions were cast on polystyrene plates and the solvent was allowed to evaporate at room temperature. Films of the pure polymers (collagen and PVA) were obtained this way.

Mechanical testing. Rectangular samples were prepared from the bulk material. The specimens were placed into the water for 24 hours at 10 °C in order to obtain samples in hydrogel form. The uniaxial tensile tests were performed on the Zwick/Roell testing machine (Messphyssik, Fürstenfeld, Austria), Fig. 1. The experimental Cauchy stress (σ) of the samples elongated within uniaxial tension was computed according to Eq. 1.

$$\sigma = \frac{F}{S}(1+\varepsilon) \tag{1}$$

In Eg. 1 F denotes applied force, ε is engineering strain and S is reference cross-sectional area. The initial stiffness up to 0.1 of deformation ($E_{0.1}$), ultimate tensile stress (σ_F) and deformation at failure (ε_F) were obtained from the stress-strain curves.

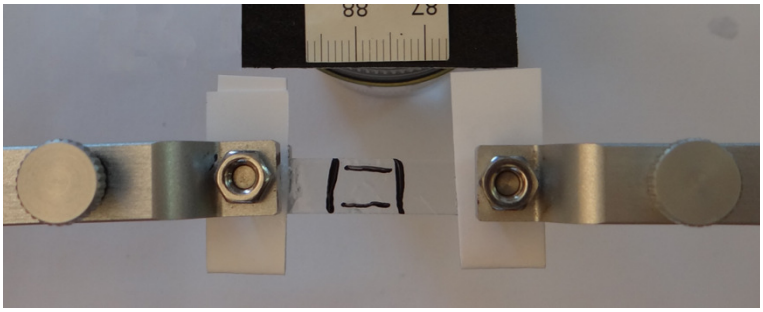

Fig. 1. The sample mounted in the testing machine. The black marks were used to identify the deformation in longitudinal and transversal direction, respectively.

Results

The resulting stress-strain curves and the initial linear region for the deformation up to 0.1 for native and denaturated collagen-PVA are plotted in Fig. 2. The initial stiffness, ultimate tensile stress and deformation at break-point for different ratios of PVA/Coll are listed in Table 1.

Table 1. The initial stiffness ($E_{0.1}$), ultimate tensile stress (σ_F) and deformation at failure (ε_F) for different ratios of PVA/Collagen.

PVA/Coll	*Native collagen + PVA*			*Denaturated collagen + PVA*		
	$E_{0.1}$ [kPa]	σ_F [kPa]	ε_F [-]	$E_{0.1}$ [kPa]	σ_F [kPa]	ε_F [-]
0	37.2	56	0.67	207.1	130	0.38
0.3	128.9	340	0.75	397.6	290	0.49
1	435.7	380	0.45	621.5	530	0.55
2	649.4	749	0.59	991.3	998	0.68
3	855.5	827	0.53	1724.5	2485	1.06

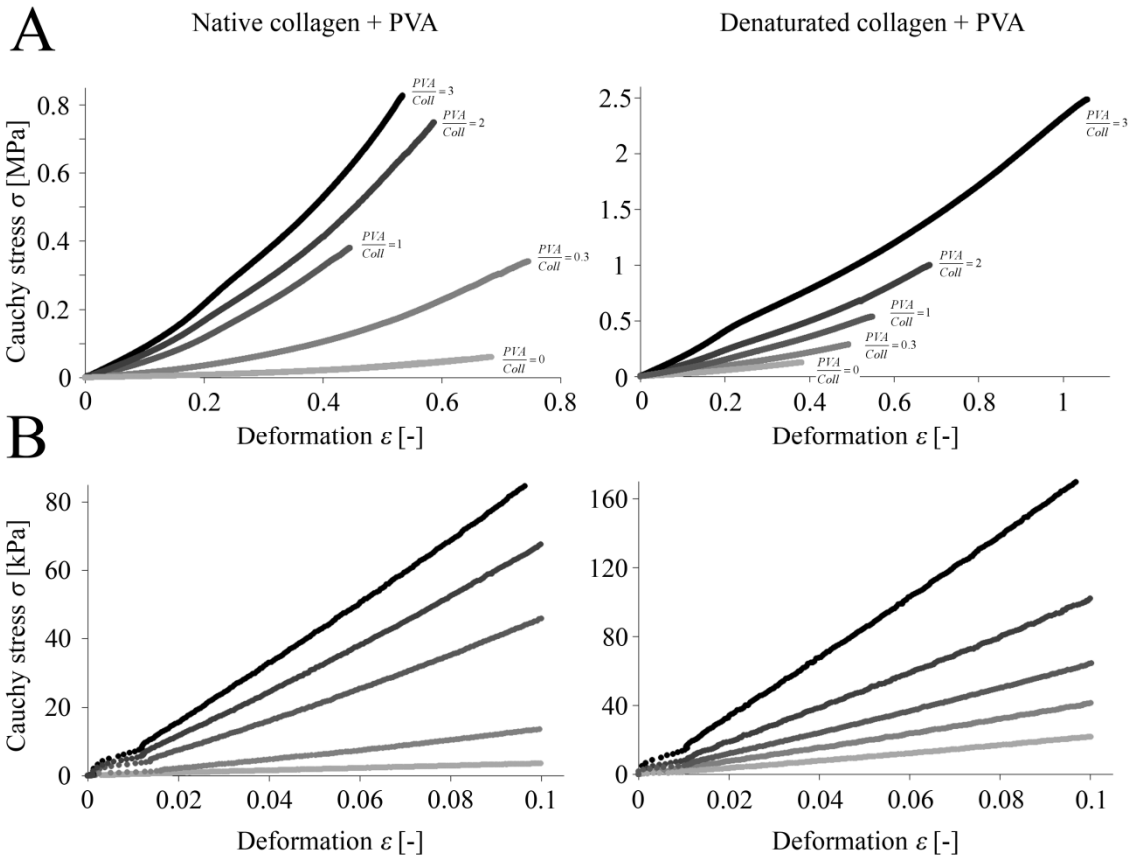

Fig. 2. Panel A - Stress-strain curves for different ratios of PVA/Collagen. Panel B shows the initial linear region for the deformation up to 0.1 for native and denaturated collagen, respectively.

Conclusions

It was proved that the material prepared only from collagen is highly compliant with low ultimate tensile stress. Increasing concentration of PVA leads to higher values of ultimate tensile stress and initial stiffness of the material. Samples prepared from denaturated collagen showed the higher σ_F and $E_{0.1}$ in comparison with those prepared from native collagen. It was also shown that increasing amount of PVA in blends with denaturated collagen leads to the higher deformation at the failure. The results suggest that final mechanical properties of the material can be modulated through concentration of PVA and we could expect successful application of the collagen-PVA biomaterial for tissue engineering.

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