Original

The Effect of Polarized Laser Radiation on Viscoelastic Properties of Soft Tissue

Amjadi A.*, Motaghian F.

Biomedical Physics and Laser Laboratory, Physics Department, Sharif University of Technology, Tehran, Iran

Abstract

Background: Laser-tissue interaction on low-level laser therapy (LLLT) has widespread medical applications (*e.g.*, improved wound healing). The tensile strength of radiated tissue by LLLT is known to be increased mainly because of cross collagen bands developed after radiation.

Objective: In this work, we studied the instantaneous effect of radiation of polarized laser beam on the viscoelastic tissue properties.

Methods: The viscoelastic behavior of tissue was investigated by experimental measurement and analyses of stress-strain plots.

Result: LLLT increased the viscoelastic properties of the irradiated soft tissue. The maximum variation in viscoelasticity was attained when the direction of laser polarization is parallel to the tissue stretch vector. The variation also depended on duration of laser irradiation.

Conclusion: Viscoelastic properties of soft tissue can be changed by polarized laser radiation.

Keywords

Viscoelastic behavior; He-Ne laser; Polarization; Exposure time; Collagen fiber; Soft tissue; Tensile strength

Introduction

One of the considerable applications of laser in medicine and biology is to use it to increase the tensile strength of soft tissue. As the behavior of the intrinsic stress-strain relationships of a tissue describes its viscoelastic module, independent of its geometry, investigating the tissue viscoelasticity is the best way to characterize its mechanical behavior [1]. The low intensity lasers can cause chemical reactions in tissue without any considerable thermal effect or pain. Therefore, laser is considered an important treatment modality [2]. So far, the effect of He-Ne laser therapy for improving biomechanical properties (*e.g.*, the maximum load, stress, strain, energy absorption and toughness) of a wound, has been investigated in different studies [3]. Some reports revealed that concomitant laser therapy with other treatment modalities speeded up wound healing [4]. Reshaping cornea and cartilage is another possibility that can be done by laser [5]. Morphological studies showed the effect of laser polarization on the healing process [6, 7]. It has also been shown that linearly polarized light can penetrate more in biological tissue [8].

After laser therapy, structural changes in extracellular matrix happen; following these changes, electrostatic or covalent bands may occur in

*Corresponding author: Amjadi Ahamd, PhD, Biomedical Physics and Laser Laboratory, Physics Department, Sharif University of Technology, 11365-8639, Azadi Ave, Tehran, Iran
Tel: +98-21-6616-4511, E-mail:amjadi@sharif.edu

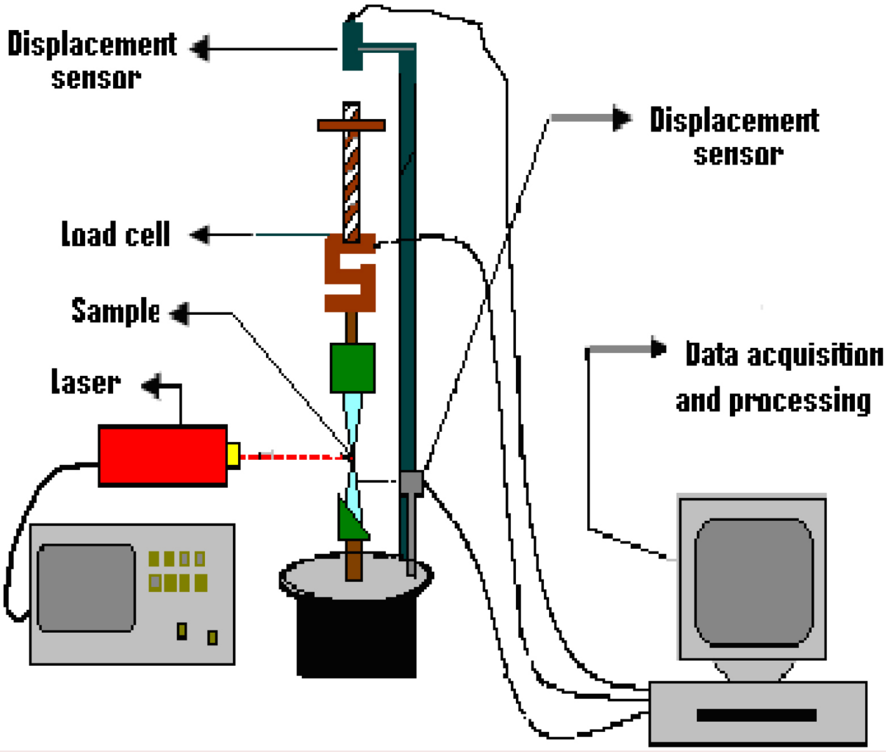

Figure1: Schematic diagram of tensile machine

the protein structure of collagen fibers [9].

So far, some mechanical investigations have been made on tissue viscoelastic properties, but none of them has described the instantaneous effect of polarized laser on the viscoelasticity properties of the tissue. The objective of this study was therefore to measure the changes in the viscoelastic module of soft tissue treated with laser and to determine the optimum polarization and duration of laser radiation.

Methods and Materials

To investigating the effect of polarization of laser on soft tissue we considered several parameters including the following variables: A) the change in viscoelastic module of the soft tissue (Δk); B) duration and polarization axis of laser radiation; C) type of laser (He-Ne) and tissue temperature (300 °K); and D) tissue kind, hydration and speed of stretching the tissue.

Sample tissues were selected from pleura of an animal. The specimens had homogenous distribution of collagen and elastin fibers. We used 36 samples measured 2×2×0.1 cm^3 kept in formalin solution. After applying the necessary tension to all samples, they were divided into three groups: Group $L_{\perp}$ in which samples were irradiated with He-Ne laser with the polarization vector perpendicular to the direction of tissue stretch; group $L_{\parallel}$ in which samples were irradiated with He-Ne laser with the polarization vector of parallel to the direction of tissue stretch. The duration of radiation was 10, 20 and 30 sec. The non-radiated group, R, which served as the control group. To keep the humidity of the samples constant, measurement was made soon after tissue irradiation.

We measured the slope of stress-strain curve, viscoelastic stiffness, to assess the strength of the tissue. External forces applied to the samples and the resultant changes made in their length were measured using a tensile machine (Fig. 1). For all samples, the slope of diagrams and relative changes of diagram slopes (Δk) were calculated before and after applying radiation. The Δk was then normalized to one. The

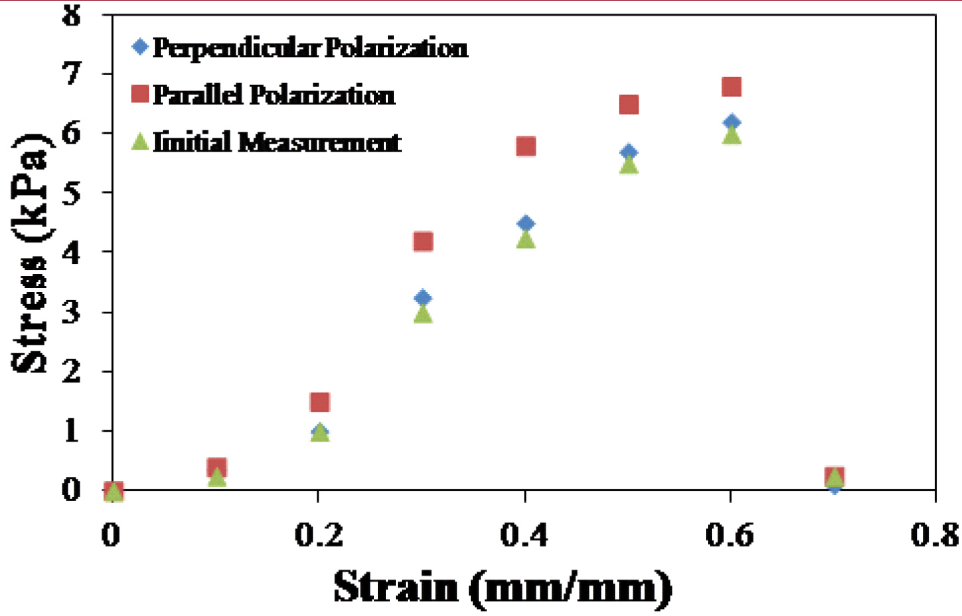

Figure 2: Representative stress-strain curve of a collagen matrix: blue marers show the initial measurements.

relative variation in the slope of stress-strain curves were designated as $\Delta k_{\perp}$, $\Delta k_{\parallel}$, and Δk_R for $L_{\perp}$, $L_{\parallel}$, and R groups, respectively.

Mechanically, the stress-strain curve of all materials behave similarly and has "toe," "linear," and "failure" regions that can be find in all of them [10]. Our experiments were conducted in the linear region of the curve where the slope of stress-strain curve is changed between 20% and 80% of the maximum stress (Fig. 2). Data were analyzed by Minitab®. One-way analysis of variance (ANOVA) was used to compare means of variables among the studied groups. A $p<0.1$ was considered statistically significant (type I error of 10%).

Results

Figures 3, and 4 indicate the influence of po-

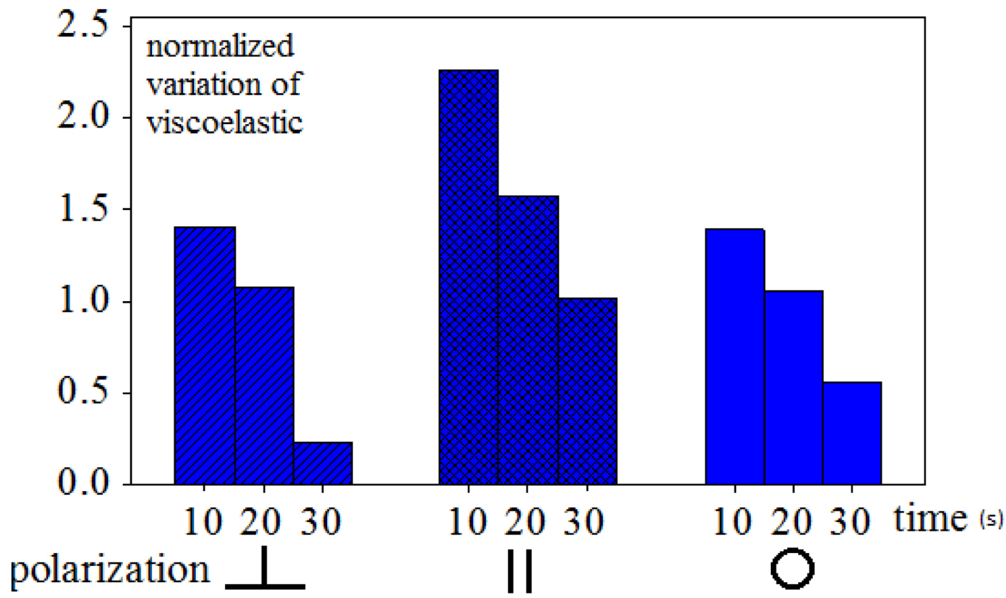

Figure 3: Normalized variation of viscoelasticity of all samples irradiated for various durations and polarizations

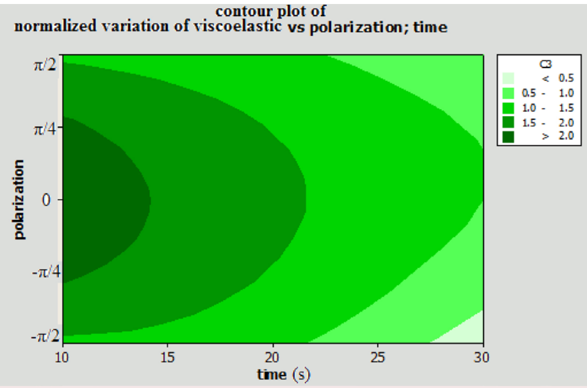

Figure 4: Contour plot of normalized variation of viscoelasticity of all samples irradiated for various durations and polarizations

larization and duration of irradiation on viscoelasticity of the irradiated tissues. Δk was positive in all groups indicating that the slope increased after radiation (second stage), *i.e.*, tissues showed more strength and extra-force is needed to make the similar changes. In all groups, samples that received radiation for 10 sec, showed more different behavior comparing with other samples. The results showed an increase in the viscoelasticity of tissues radiated with parallel polarized laser beam.

Discussion

Appropriate polarization direction can affect viscoelastic behavior of the tissue. The viscoelastic behavior of tissue can be investigated trough studying the stress-strain diagram. Biological tissues are made of collagen, elastin fibers and other proteins. Irradiation of these tissues would cause aggregation of their proteins to absorb the laser energy, which joins parallel fibers in tissues and makes cross-linking between them, forming the collagen cross bands [11]. These cross-linking created between amino acid hydrocarbons of each fiber effects the viscoelastic stress-strain response of the tissue. The strength produced due to the created collagen bands in irradiated samples has a component in tension direction and effects the tissue mechanical properties, such as viscoelasticity module.

After irradiation, the collagen fibers are changed and their regularity are lost. Several different changes in the collagen bands are investigated during the skin irradiation. Some come together and form ropes and lose part of their periodic structure. Some are inflamed and their diameter (70–80 nm) is doubled, but their periodic structure is not changed. Some are dissolved and completely lose their periodic structure [12].

Due to the high viscoelasticity of parallel-polarized irradiated tissues comparing with other polarization directions, we concluded that parallel polarized laser radiation might organize collagen bands completely. Therefore, it can be concluded that the rate of collagen come back instantly after irradiation is more than collagen renewal in the healing process [13].

Biological studies are based on the fact that changes in the extracellular matrix occur first; they are then followed by electrostatic and covalent bonding of tissue proteins [14].

The orientation of collagen bundles is parallel to the tension axis [15]. The effect of laser radiation on collagen's dipole can be considered, too. The torque acting on dipoles rotates them in the direction of the electrical field vector [16]. Considering this phenomenon, we can explain our results more precisely. We considered the electrical field vector of the polarized laser radiation being aligned with the tension direction; the electrical field imposes a torque on collagen's dipole parallel to the fibers' direction; this leads to more regularity in collagens distribution. Further investigations on the molecular changes, which occurs during laser radiation, may help better understanding of the phenomenon.

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