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Viscoelastic properties of the autologous bypass grafts: A comparative study among the small saphenous vein and internal thoracic artery

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Abstract Internal thoracic artery (ITA) and small saphenous vein (SSV) are two viable conduits for coronary artery bypass grafts. The aim of this study was to investigate the viscoelastic behavior of the small saphenous vein and internal thoracic artery under compressive and tensile loadings at body temperature. The dynamic mechanical analysis was used to measure the viscoelastic properties of the ITA and SSV at both the desired temperature and load frequency range. Storage modulus, loss modulus as well as phase angle of both the blood vessels were measured at the temperature of 37 ± 1 °C and under a sinusoidal load with the frequency range of 1–2 Hz. The mean storage and loss modulus of the SSV were both higher than that of the ITA. Furthermore, the SSV showed a higher stiffness and internal friction compared to those values under the tensile load. While ITA was stiffer under the tensile load, no considerable difference was observed among the compressive and tensile loss modulus. A more intense viscous behavior was observed under the radial direction. The results also revealed that the SSV has much higher stiffness whereas less viscous behavior compared to the ITA, especially in the radial direction. The results may have implications not only for understanding of the viscoelastic time-dependent mechanical behavior of the ITA and SSV but also for tissue

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engineering applications to make scaffolds according to the real time-dependent viscoelastic mechanical properties of these arteries and veins.

Introduction

The small saphenous vein (SSV) is a superficial vein of the leg. It originates from the lateral side of the dorsal venous arch and passes behind the distal end of the fibula and up the back of the leg to penetrate deep fascia, and finally join the popliteal vein posterior to the knee.[1] The SSV is in danger of becoming distended or having thrombosis.[2] The internal thoracic artery (ITA) arises as a major branch of the subclavian artery in the neck. It passes posterior to the clavicle and the large veins in the region and anterior to the pleural cavity. Then, it enters to the posterior side of the thoracic cavity in the ribs and anterior to the transversus thoracis muscle and continues to descend giving off numerous branches.[1] Both of these blood vessels are commonly used for treatment of coronary artery disease as bypass graft,[3–6] and both are vulnerable to be occluded and lose their patency.[4,7]

Dynamic mechanical properties refer to the response of a material as it is subjected to a periodic force. These properties may be expressed in terms of a dynamic modulus, a dynamic loss modulus, and a mechanical damping term. Specifically, in dynamic mechanical analysis (DMA), a variable sinusoidal stress is applied, and the resultant sinusoidal strain is measured. If the material being evaluated is purely elastic, the phase difference between the stress and strain sine waves is 0°. If the material is purely viscous, the phase difference is 90°. However, most of the biological materials have viscoelastic material properties and exhibit a phase difference between those extremes. Furthermore, as DMA is a thermal analysis technique, it is well suited to analyze the viscoelastic properties of a biological material under the body temperature.[8,9]

Autograft for coronary artery bypass graft has been used for a long time. Johnson et al. expanded the application of the saphenous vein autograft by using it as a bypass channel for the left coronary artery.[10] Furthermore, Bailey et al. used the internal thoracic artery instead of saphenous vein as a bypass graft for the coronary artery.[11,12] Since then coronary artery bypass grafting has grown to become one of the most common operations in the world. Even though these bypass graft had shown a good performance, they can be occluded and fail to provide a suitable channel for the blood to flow. Therefore, understanding the mechanical behavior of these materials can provide important insights into their encounter complications. Several studies have investigated the mechanical properties of SSV and ITA. Compliance and elastic properties of the saphenous vein were investigated by Walden et al.[13] Zamboni et al. measured the compliance of the both great saphenous vein and SSV.[14] Furthermore, Chamiot-Clerc et al. compared the elastic mechanical properties of the internal mammary artery to the radial artery.[15] Pressure—diameter, pressure—axial force, circumferential and axial stress—strain relations, and dimensions of porcine coronary artery and internal mammary were compared by van Andel et al.[16] The internal diameter, burst pressure, suture retention, and compliance of the internal mammary artery and saphenous vein in respect to the tissue engineered blood vessels have compared.[6]

So far, there has not been a study on the viscoelastic properties of either the ITA or SSV. The viscoelastic behavior of the blood vessel can be important for their performance, because unlike the elastic materials the stress at a given point of a viscoelastic body depends on the strain at that time, and on the strain from the past time which affects the stress. Furthermore, if a material has viscoelastic characterization, due to the damping behavior of the viscous part, its stress and strain response to the loading and unloading would be different. However, the stress—strain relationship during the loading and unloading for each cycle is unique.[8] Hence, investigating the behavior of the ITA and SSV from a viscoelastic point of view can give us much needed information about these blood vessels. In this study, the viscoelastic characterizations of the ITA and SSV under cyclic load and at body temperature, as two options for being used as graft for coronary artery bypass grafting, have been investigated.

Materials and methods

Specimen preparation and mechanical testing

Four SSVs and four ITAs were collected from two male subjects with healthy respective blood vessel. All subjects who donated blood vessel in this study did so voluntarily after giving informed consent under the ethical rules of Baqiyatallah University of Medical Science (BUMS). Five centimeter of each vessel was cut for further use. The SSVs and ITAs then were immersed in solution of 0.90% w/v of NaCl at 4—5 °C before the test. Afterward, both vessels were transversely cut open using a surgical scalpel. Then, two specimens were cut from each vessel. Thickness, length, and width of each specimen were measured via a digital caliper (Insize, Vienna, Austria). The size of the specimens is listed in Table 1.

Table 1 The dimensions of the specimens.

	Thickness (cm)	Length (cm)	Width (cm)
ITA tension specimen	0.80	7.14	7.45
ITA compression specimen	0.70	14.20	5.00
SSV tension specimen	0.40	7.14	7.51
SSV compression specimen	0.43	11.58	5.56