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Investigating Effect of Compression Stocks on Tissues of Legs

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Abstract

Introduction: Doctors usually assume that the use of compression stockings can put pressure on the tissues of the leg and can reduce the diameter of the vein and help prevent vein thrombosis. However, a few contradictory results have been published with this assumption in several studies.

Objective: This paper evaluates the effects of compression stockings on the tissues of the legs. Material and

Methods: To do this, we simulate the part of the leg utilizing an MRI photo and Mimic material software and then analysis it based on finite element approach in ANSYS software.

Results: The obtained results show that the contribution of MCS compression stockings to deep-vein diameter variations is negligible, so that these effects were 3% and 9% for in standing position and sitting state, respectively. Also, the results illustrate that the greatest effects of the transverse diameter variation of the vessel occurred with the activation of the muscle tissue.

Conclusions: Therefore, the use of compression socks can exert pressure on the leg tissues and can reduce the diameter of the vessel and help to prevent vein thrombosis.

Keyword: Compression stocks, Boundary conditions, MRI image, Finite element method

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1. Introduction

Deep vein thrombosis has always been a challenge in trauma to the leg and ankle [1-4]. The main reason for this problem is that if prevention and treatment is not sufficient and deep vein thrombosis can occur, it can lead to phlebitis, pulmonary embolism, and ultimately death [5-9]. Also, intravenous thrombosis can cause venous insufficiency, chronic leg swelling, dermatitis, and ulcerous lesions [1]. Occurrence of deep vein thrombosis can have different causes [10-11]. It has been reported in various studies that immobilization is one of the main causes of deep vein thrombosis and subsequent pulmonary embolism [12-14].

Nowadays, many patients with leg or ankle fractures and also with severe ankle sprains (ligament damage) are treated with motionless using plaster or short splint. It is said that this therapeutic technique can cause deep vein thrombosis due to immobilization

and inactivation of the pumice function of the leg muscles and ankles [15]. One of the most suitable options for treating patients with deep vein thrombosis is pressure socks [16]. In many studies, the use of this method of treatment has been successful [17]. A change in the vessel's diameter and its reduction by compression socks prevent the blood transfusion and can be a kind of biomechanical treatment [18]. The treatment of deep vein thrombosis was reported to be between 1.1 and 20% in various studies [19, 20]. However, these thromboses can be dangerous after the treatment of ankle sprain or leg or ankle fracture or short neck fractures [21, 22].

Currently, a large percentage of patients who suffer from lower limb trauma are treated with compression socks in European treatment centers [23]. Lack of Information about deep vein thrombosis in soft tissue damage is very high. Only study conducted on the treatment of intravenous thrombosis after the treatment of ankle fractures by compression stockings is related to Pierre et al. in their latest study in 2014. The aim of this study was to evaluate the changes in the tissue of the leg and the tissue geometry of the vessels when using compression stockings.

2. Material and Method

In this study, an MRI image to create a geometric model has been used. Resonance imaging of a part of tissue can provide researchers with a suitable data about simulating and evaluating tissues and biomechanics. Considering the geometric modeling of muscle, fat, skin and bone tissues as well as the study of the effects of vascular deformation, favorable results in tissue engineering studies and biomechanics of the internal organs of the legs and muscles around it can be obtained. The study of muscles in finite element techniques and the discussed simulations above can be a useful solution for such studies.

2.1. MRI imaging

The original MRI data were obtained from a volunteer patient who was 45 years old. Pictures of the patient's left leg were photographed with 15 shear slides of leg tissue to the cross-section of 3.9 mm and a length of 9.78 mm for using on geometric modeling (Figure 1).

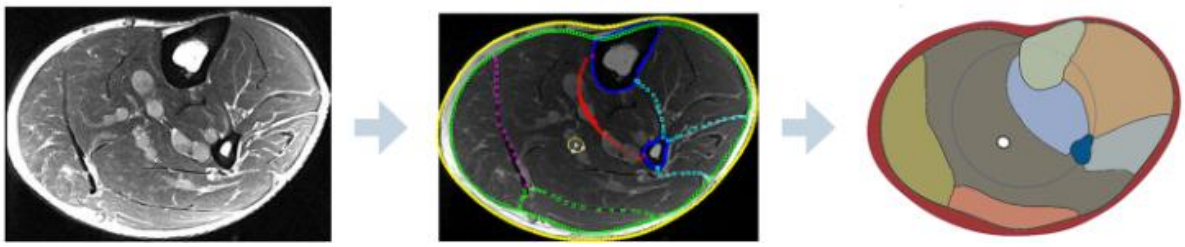

Figure1. The boundaries of the leg tissues in the Mimic Materials 17 software and the fabrication of tissue geometry through MRI slides.

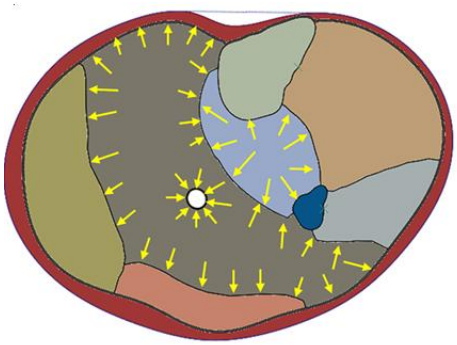

Figure2. Biomechanical function of applying boundary conditions for the leg tissue

2.2. Making a geometric model for foot

Different components of the leg tissue were identified and bound in the MRI photograph in the Mimic Materials software (Version 17). Skin and bone tissues were automatically determined using the densitometric measurements in the software. The fat tissue and the four parts of the muscles around the tibia (ATC), side muscles (LC), posterior superficial muscles (SCP) and deep posterior muscle (DPC) were identified in the software, respectively. The simulated SPC section is divided into two muscles of the solos and gastrocnemius. The vascular model is simulated from the soles inside muscle veins. Due to most clinical studies, the most commonly occurring thrombosis are caused in this area.

The muscular image is simulated with the intramuscular vessel in figure 2. The arrows of figure 2 represents the biomechanical function of applying boundary conditions in the analysis. These boundary conditions include muscular pressure entering the vessel and lateral pressure. In the simulation of the vessel geometry, the section of interior vessel is defined as a circle, which is suited to the major cross-sectional area of the vessel.

2.3. Finite Element Analysis

Musculoskeletal modeling is performed in the Mimic software and the separation of leg tissue is saved in IGS format that can be transferred to the ABAQUS / CAE software version 2018 for finite element analysis. The supposed thickness of the veins wall is assumed to be 10% of the lumen vein, which is the average of the vein circular section and including in the studies by Martiz and colleagues [24]. This defined thickness in the vessel modeling is made in order to complete the vessel wall geometry [25-26]. For the muscles, the exterior thickness was considered 1 mm. The soft tissues were defined using a hyperelastic model of the nook theory in the software. These values used to determine the tissue properties have been extracted from previous studies (Table 1) [27-29].

Our model was loaded with two states of standing and sleeping. The MCS used in the study was determined using the elastic law of linear structural materials [27]. Bone tissue was considered as rigid body in this study.

Loading of blood pressure and pressure on the wall of the vessel was applied as a uniform and constant compression on the wall of the vessel. The amount of applied pressure on the wall of the vessel was 15 mm Hg for rest mode and 90 mm Hg in standing position. For arterial pressure, the amount of applied charge was 100 and 195 mm Hg, respectively, in a rest and standing position.

The amount of applied load to the arterial pressure actually involves pressure on the vessel wall before applying the external pressure. These boundary conditions create initial stress on the tissue of the vessel wall. The stress level before applying the force on the wall of the vessel is calculated by the Laplace equation in a finite element method.

Table1: The amount of coefficients for determining the properties of materials in the study

Material	Model	Material parameters
Fat	Hyper-elastic Neo-Hookean	C_{10}=0.005 Mpa; D_1=0.14 Mpa^{-1}
Muscle	Hyper-elastic Neo-Hookean	C_{10}=0.003 Mpa; D_1=0.14 Mpa^{-1}
Skin	Hyper-elastic Neo-Hookean	C_{10}=0.1 Mpa; D_1=0.14 Mpa^{-1}
Muscular aponeurosis	Hyper-elastic Neo-Hookean	C_{10}=10 Mpa; D_1=0.14 Mpa^{-1}
MCS	Linear elastic	E=0.39 Mpa; v=0.49
Vein wall(supine)	Hyper-elastic Neo-Hookean	C_{10}=0.016 Mpa; D_1=62 Mpa^{-1}
Vein wall (standing)	Hyper-elastic Neo-Hookean	C_{10}=0.14 Mpa; D_1=7 Mpa^{-1}
Artery wall	Hyper-elastic Neo-Hookean	C_{10}=0.017 Mpa; D_1=0.14 Mpa^{-1}

2.4. Finite element in ABAQUS

In this study, our outcomes were based on stress in a two-dimensional plane. Soft tissues were considered as incompressible in the analysis, and the elements were utilized using the hybrid elements with the characteristics of CPE4H and CPE3H in ABAQUS software.

The elements around the vessel were manually determined and linear hexagonal elements were used to determine the amount of stress in the vessel wall and to help the problem-solving convergence. The number of elements within the vessel was 40,000 units, and the total degrees of freedom of the elements reached 130,000 degrees of freedom.

2.5. Determine the type of collisions of tissues with each other

In determining the type of tissue with each other, the magnitude and type of each collision are given in Table 2. Since we did not find any kind of collisions between tissues in any study, we determined the properties of soft tissue according to the flexor tendon texture of the fingers.

3. Results

The distribution of the predicted hydrostatic pressure of external pressures at 15-20 mm Hg in lying state is indicated in Figure 3. The obtained results in this figure show a non-homogeneous distribution of pressure as well as being the highest pressure on soft tissues.

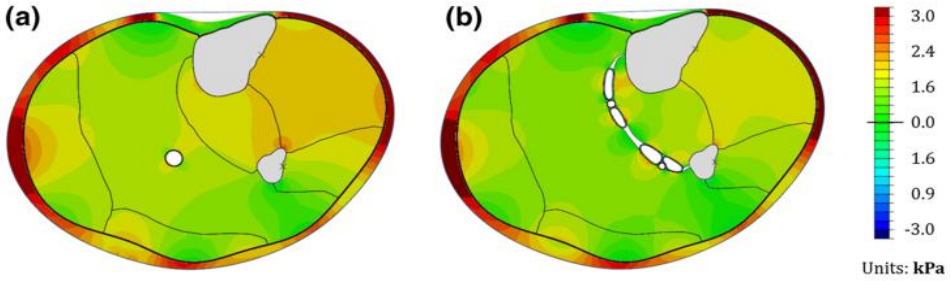

Figure 3. The distribution of pressure on the tissues of the legs; the model A standing state and B is in the sleeping state.

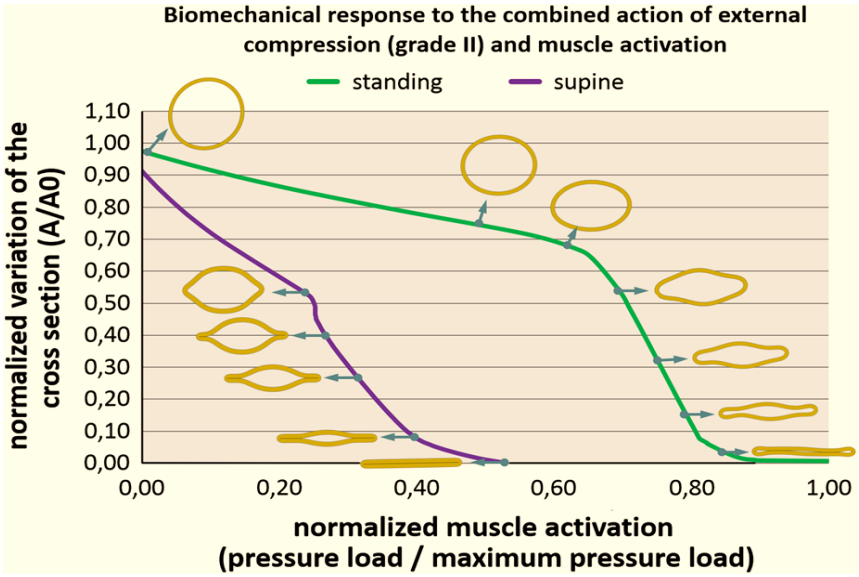

Figure 4. The response of deep intracranial muscle vessels to external tissue biomechanical pressures

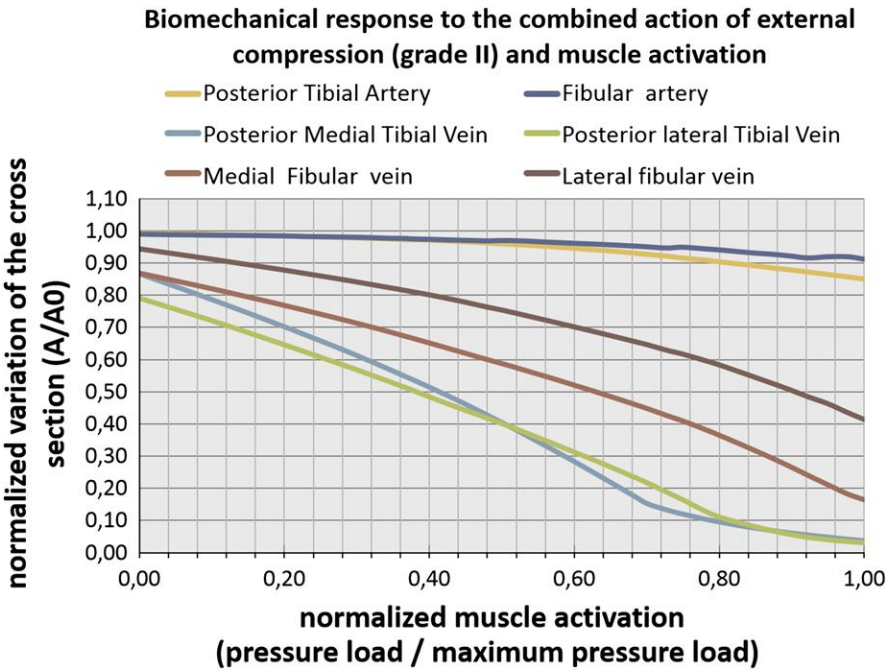

Figure 5: Biomechanical response of deep veins and arteries under external compression and internal pressure by muscle activation

3.1. The obtained results at activation of the muscles.

The responses of intravenous tissue changes during muscle activation are shown in Figure 4. When the muscle is not activated, the diagram shows normal changes and these pressures are only caused by elastic compression. Also, Figure 4 shows that the decrease in the area of the vessel is 3% and 9% for the supine state and the standing position, respectively. During the activated muscle, the diagram is presented as a combination of the changes made by elastic pressure and muscle activation. Our results indicate that the area during the active muscle has encountered a decrease in the diameter of the vein and the tissues have a higher compression and ultimately lead to tissue collapse. This pressure was less pronounced in the standing position due to the pressure on the walls of the veins in the state.

3.2. Intravenous biomechanical response between muscles

The biomechanical response of the muscle vessels is shown in Figure 5. Each component in the chart is individually used. In the observation of reactions, lower arteries of the tibial dorsal vessels were affected by the pressure of the tissues. These observations were identical in both cases without activating the muscle and with activating the muscle. At the time of the analysis, 20% reduction in the transverse area of the vessel was observed due to pressure by compression socks while close to 80% remnant was for muscle activity.

4. Discussion

The benefits of MCS compression stockings are generally in clinical practice reducing the diameter of the vessel in the tissue and, as a result, blood collection in the pressurized area. For lower deep veins, these clinical results are contrasted with the reported outcomes. The aim of this study was to evaluate the tissue biomechanics and its changes based on the vessel's response to intra-and extrinsic pressures. The results of this study illustrate that using MCS compression stockings based on clinical imagination do not have the effects on the deep vein surface changes in standing position (Figure 4).

In a study of 30 volunteers, which included 17 normal legs and 13 varicose feet, compressive stockings with

pressures of 20-30 mmHg for vessels inside tissue were reported to have close results in comparison to our outcomes. In the results, it was shown that limiting deep veins in the standing position are related to muscle contraction and the pressure of the wearable MCS socks is not affected in this regard.

5. Conclusions

In this study, we designed a biomechanical tissue model using finite element technique for the shin region to investigate the effects of deep intrinsic tissue vessels during elastic compression and muscle contraction. Combining the activity of the internal tissues helps understanding the effect of the MCS compression stockings. Particularly in the results, we observed that blockage of veins and its cross-sectional changes are more related to the activity of internal muscles than the use of compression socks. In the deep veins, all of the responsibility for blocking these veins was shown in the internal muscle activity. Thus, the results of this study are consistent with many studies and it can be stated that compression socks have no effect on the deep vessels. In the future, it is suggested that in order to extend the study using a biomechanical model for deep tissue veins, we also consider them in splits.

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