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Inflation-Extension Behaviour of the Human Vena Saphena Magna

KRATOCHVÍL O.[1,a], CHLUP H.[1,b], HORNÝ L.[1,c] ŠPAČEK M.[2,d], MĚŘIČKA P.[3,e],

[1]Faculty of Mechanical Engineering, Czech Technical University in Prague, Technická 4, 160 00 Prague, Czech Republic

[2]2nd Department of Surgery – Department of Cardiovascular Surgery, 1st Faculty of Medicine, Charles University in Prague and General University Hospital in Prague, U nemocnice 2, 120 00 Prague, Czech Republic

[3]Tissue Bank, University Hospital Hradec Králové, Sokolská 581, 500 05 Hradec Králové, Czech Republic

[a]ondrej.kratochvil@fs.cvut.cz, [b]chynek@seznam.cz, [c]lukas.horny@fs.cvut.cz, [d]miroslav.spacek@vfn.cz, [e]pavel.mericka@fnhk.cz

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Abstract. Saphenous vein grafts are still frequently used in both coronary and peripheral bypass surgery. Although much work is now being done to deepen our knowledge of the mechanobiology of graft remodelling, these processes are still not completely understood. To contribute to an effort aimed at filling this gap, a pressurization experiment with a tubular sample of the human great saphenous vein was carried out. Our study particularly focused on the so-called inversion point, known from arterial mechanics. Inversion point is the value of the axial prestretch at which a pressurized tube does not move axially. The experiment confirmed that axial inversion takes place in the mechanical response of the prestretched saphenous vein. This means that there is a value of the axial prestretch at which pressure-induced elongation changes to pressure-induced shortening of the inflated tube.

Introduction

Saphenous vein grafts are still frequently used in both coronary and peripheral bypass surgery especially when alternatives like the internal thoracic artery or the radial artery are not available [1,2]. In contrast to their arterial counterparts, properties of vein grafts, however, are optimized for a mechanical environment very different from arterial conditions. An obvious consequence of this fact is that immediately after surgery, remodelling processes are triggered and the vein adapts to the elevated blood pressure, flow rate, and oscillatory wall shear stress [3]. Although much work is now being done to deepen our knowledge of the mechanobiology of graft remodelling, these processes are still not completely understood [3–6].

In particular, a fully nonlinear constitutive description, validated experimentally at multiaxial stress states, is rare in the scientific literature [4–6]. To contribute to an effort aimed at filling this gap, a pressurization experiment with a tubular sample of the human great saphenous vein was carried out.

It is well known that arteries sustain significant axial prestretch in their in situ positions [7–9]. Since venous grafts are placed into an arterial position during bypass surgery, we propose to study how their mechanical response is changed by axial prestretching. To the best of our knowledge, our study is the first that focuses on the effect of axial prestretching on the biomechanical response of the human great saphenous vein.

Methods

Instead a simple inflation experiment, an inflation-extension test was carried out. In this experimental technique, a tubular sample is mounted into the pressurization setup vertically. The upper end of the tube is fixed, whereas the lower end can freely move in an axial direction. The axial prestretch was induced by hanging a weight of constant mass at lower end of the tube. The whole set-up is illustrated in Fig. 1. The loading protocol comprised of 8 quasi-static pressurization cycles from 0 to 20 kPa at a specific axial weight.

The mechanical response of the sample was recorded onto a PC. It consisted in digitization of the pressure signal measured with pressure transducer Cressto (0 – 30 kPa, 500 Hz) and in the recording of digital photographs of the deformed sample (two 5MPx cameras at 20 Hz). In the data post-processing, the deformation of the sample was determined with the help of an in house developed image analysis procedure, based on edge detection implemented in Matlab. In a final step, both pressure signal and measured deformation were synchronized.

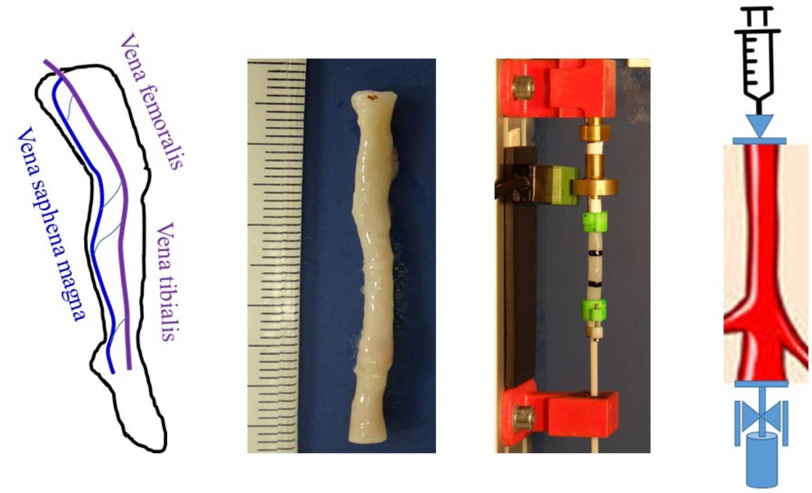

Fig. 1: Left panel shows a sketch of the lower extremity with a position of the great saphenous vein. The two middle panels display the sample of the great saphenous vein before and after mounting to the experimental setup. Finally, the right panel depicts a scheme of the inflation-extension experiment (pressurization and hanging mass).

Results

Figure 2 shows the results of the experiment. The first panel (from left) shows the pressure–circumferential stretch (the ratio of current to reference radius of the inflated tube) dependences obtained under five different values of axial preload (0, 10, 50, 200, and 500 g). The second panel depicts pressure–axial stretch (the ratio of the current to reference length of the pressurized tube) curves obtained in the same experiment. All depicted curves correspond to the loading part of the eighth cycle, when the sample exhibited a preconditioned response.

Two mechanical properties are clearly visible on the graphs: First, in axial response, it is a presence of the inversion phenomenon, at which pressure-induced elongation changes to pressure-induced shortening (cf. red curve, 0 g, and yellow curve, 50 g, in the second panel). It is worth noting that at the inversion point, which can be roughly identified with orange curve (10 g), no work is done on axial displacements, because the tube does not axially move. It follows that all the mechanical work of the loading pressure is carried out by radial distension of the tube at such a point.

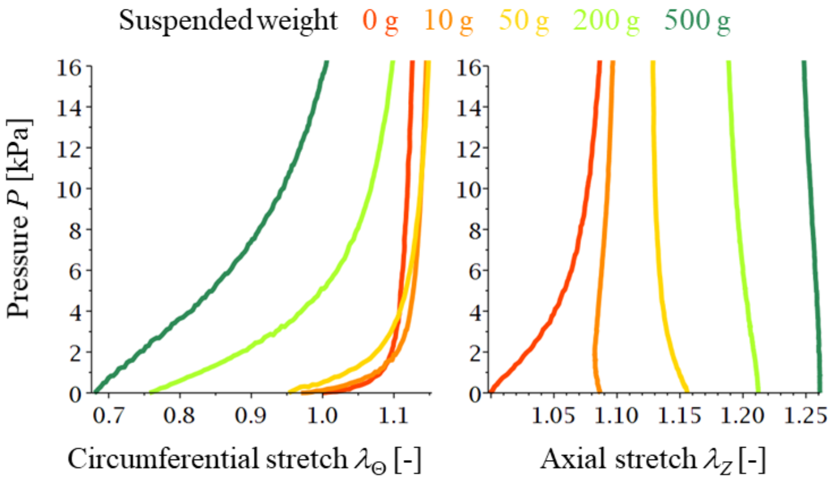

Fig. 2: Left panel shows pressure–circumferential stretch curves and the right panel displays pressure–axial stretch relationships obtained with different axial load. A colour indicates weight used as described above the image.

Table 1: Circumferential stiffness at 10 kPa

Suspended weight [g]	Circumferential stiffness [kPa]
0	740.9
10	695.8
50	416.3
200	132.8
500	70.57

The second interesting phenomenon is related to a stiffness of the pressurized tube. When curves on the left panel are compared with each other, notices that their tangents made at a given pressure have lower slopes when created on prestretched responses. In Figure 2, compare for instance green curve (500 g) and red curve (0 g) at 10 kPa. For more convenience, specific numerical values are listed in Table 1. It is clear that there is a value of the pressure, for which the axially prestretched tube exhibits more compliant response than the non-prestretched one. Such behaviour is known from arterial mechanics [8], but has not been discussed in the context of venous physiology so far.

Conclusions

Our results suggest that axially prestretched veins show similar phenomena to prestretched arteries. In particular, the prestretch reduces their stiffness during pressurization, and pressure-induced elongation may change to pressure-induced shortening. It follows that axial prestretch could offer a mechanism for how the response of venous grafts could be pre-modulated.

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