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# Fluid dynamics in helical geometries with applications for by-pass grafts

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ABSTRACT

By-pass graft failure is mainly caused by progressive intimal hyperplasia at graft anastomosis and restenosis. A helical graft induces a swirl flow pattern at the outlet section of the graft, and that can reduce the effects that cause the graft failure. This paper analyses the efficiency of helical geometries in terms of helicity and vorticity. Twelve different configurations, with one, two and four turns and different values for helix amplitude were considered for numerical analysis in steady and laminar conditions, associated with Re = 151 and Re = 377. Results show that high number of turns and high amplitude induces significant variations for helicity and vorticity. We can assume, that in the conditions of our study, the most appropriate geometries for obtaining at the outlet section a swirl flow pattern, with applications for by-pass grafts, are the configurations with four-turns and amplitude of 0.3*D* to 0.5*D*, associated with helical geometry diameter *D*.



## 1. Introduction

There are numerous applications where a swirl flow pattern development is needed. Starting from thermal [1] and chemical engineering [2] or medical applications [3] requirements, researches are conducted strongly related to process and phenomena optimization. A possibility for swirl flow development is described in the literature by using helical configurations [4]. The main advantage of this kind of geometries is the increase of particle mixing inside the specific zone associated for different applications or heat exchange efficiency, modifying the stagnation point or the particle residence time [1,2,4].

In the last period many applications of helical geometries have been developed in the field of medical use (e.g. in coronary by-pass surgery, vascular surgery, stenting procedure, dialysis, etc.). More and more researches are conducted in the field of helical geometries with medical applications in by-pass surgery. A critical complication in this type of surgery is represented by graft failure, mainly caused by progressive intimal hyperplasia at graft anastomosis and restenosis [5].

It is known that in human cardiovascular system there are regions with natural helical flow pattern, such as the human aorta [6,7]. The appearance of stenosis in these regions is low reported. Over the years, there have been presented numerical, experimental and clinical studies that show the efficiency of different types of grafts (e.g. straight, S-type, helical) used in by-pass surgery [5,8–11]. As presented in the literature, graft patency increases in case of helical grafts [4,5]. Zhan et al. [12] suggested that swirling blood flow improve the patency by suppressing acute thrombus formation, whereas Morbiducci et al. [7] consider that swirl flow prevent the excessive dissipation of energy by limiting the flow instability in arteries.

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**Nomenclature**

| | |
|---|---|
| $x(t), y(t), z(t)$ [m] | Cartesian coordinates of a point |
| $A$ [m] | helix amplitude |
| $t$ [rad] | angular parameter, $0 \le t \le 2\pi$ |
| $l_p$ [m] | helix pitch, $l_p = 2 \cdot \pi \cdot B$ |
| $L$ [m] | helix total length |
| $n$ [-] | number of turns |
| $\overline{R(t)}$ | position vector of a point with coordinates $(x(t), y(t), z(t))$ |
| $s$ [m] | curve arc length |
| $k$ [1/m] | helix curvature |
| $H$ [m/s$^2$] | helicity |
| $V$ [m/s] | velocity |
| Re [-] | Reynolds number |
| $p$ [Pa] | pressure |
| $D$ [m] | tube internal diameter |
| $\rho$ [kg/m$^3$] | density |
| $\nu$ [kg/ms] | kinematic viscosity |
| $\omega$ [1/s] | vorticity |
| $\tau$ [1/m] | helix torsion |

Helical graft efficiency is described in the literature by different parameters. For example, Zheng et al. [8] consider relevant the shear rate distribution whereas Morbiducci et al. take into consideration helicity [7] and oscillatory shear index [6]. Ha et al. suggest both swirling intensity and helicity, and the Germano number [4]. Local variations of wall shear stress is associated with regions such as branching or bifurcations, where flow velocity and shear stress is reduced and flow departs from unidirectional patterns, favoring atherogenesis, by inducing the vascular response of the endothelium [6,13].

The outline of the present paper was to analyze the efficiency of helical grafts by evaluating helicity and vorticity associated with the outlet section, in case of geometries with different number of turns and helix amplitude.

## 2. Numerical approach

Fluid dynamics tools permit a non-invasive investigation of simple and complex geometries. The present paper analysis the efficiency of helical geometries by evaluating hemodynamic parameters such as helicity and vorticity associated with fluid flow through geometries with circular constant cross-section, and different values of amplitude and number of turns.

### 2.1. Geometry generation

We define a helix in three-dimensional Euclidian space as a circular curve whose centerline is located on a straight, circular cylinder. Equation describing the helix parameterized by the angular parameter is the following (Eq. (1)):

$$\begin{cases} x(t) = A\cos t \\ y(t) = A\sin t, \ldots 0 \le t \le 2\pi \\ z(t) = Bt \end{cases} \tag{1}$$

Each point from the curve could be described by its position vector:

$$\overline{R(t)} = x(t)\bar{i} + y(t)\bar{j} + z(t)\bar{k} \tag{2}$$

The Eq. (2) could be canonically parameterized using the curve arc length described by (3):

$$s = \int_0^t \sqrt{\left(\frac{dx}{dt}(t)\right)^2 + \left(\frac{dy}{dt}(t)\right)^2 + \left(\frac{dz}{dt}(t)\right)^2}\, dt \tag{3}$$

The graft model was created with four-turn helical pitches. The helical graft model has a circular cross-section (Fig. 1) for all investigated geometries (different helix amplitude).

The helix curvature ($k$) and torsion ($\tau$) are described as following:

$$k = \frac{A}{A^2 + B^2} \tag{4}$$

$$\tau = \frac{B}{A^2 + B^2} \tag{5}$$