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Original Research Article

Blood flows in end-to-end arteriovenous fistulas: Unsteady and steady state numerical investigations of three patient-specific cases

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1. Introduction

An arteriovenous fistula (AVF) has been a widely accepted vascular access for haemodialysis over the last 50 years [1]. Despite its commonness, it is still a weak point in the treatment due to frequent complications (stenosis, aneurysms, thrombosis, steal syndrome, etc.) that increase significantly costs of the cure [2]. The number of haemodialysed patients is still growing and growing because of ageing of the population [3], thus more and more efforts are made by many researchers in order to prolong the fistula lifetime. The majority of complications occurring in fistulas is related to abnormal haemodynamics in the anastomosis and other parts of the fistula, which means not only a disturbed flow but also abnormal values and high oscillations of the wall shear stresses (WSS). This study presents the results obtained from numerical simulations of the blood flow through three patient-specific end-to-end fistulas which were assessed to be more likely dysfunctional than the end-to-side ones [4]. Numerical methods seem to be the only opportunity to provide complete information on the distribution and range of the WSS for complicated shapes of blood vessels used for man AVF [5].

2. Material and methods

2.1. Geometrical models

In this study, 3-dimensional Computer Aided Design (CAD) models of geometries of three patient-specific fistulas reconstructed from angio-computed tomography (angio-CT) were used (Fig. 1). DICOM images were obtained three months after Q3 the fistula formation for medical reasons, thus a special permission for model acquisition with CT was not required. All large blood vessels, located in the forearm, were taken into account – radial artery, cephalic vein, large accessory veins. This approach is related to the aim of this study, which is a deeper insight into the flow through the complex fistula geometry. Authors of some other papers usually focused on the anastomotic region [6–8] only, thus they did not consider the specific flow conditions generated in a complex geometrical model. The details regarding the blood vessel CAD models, built with DICOM viewer RSR2™ and Solid Works™, were

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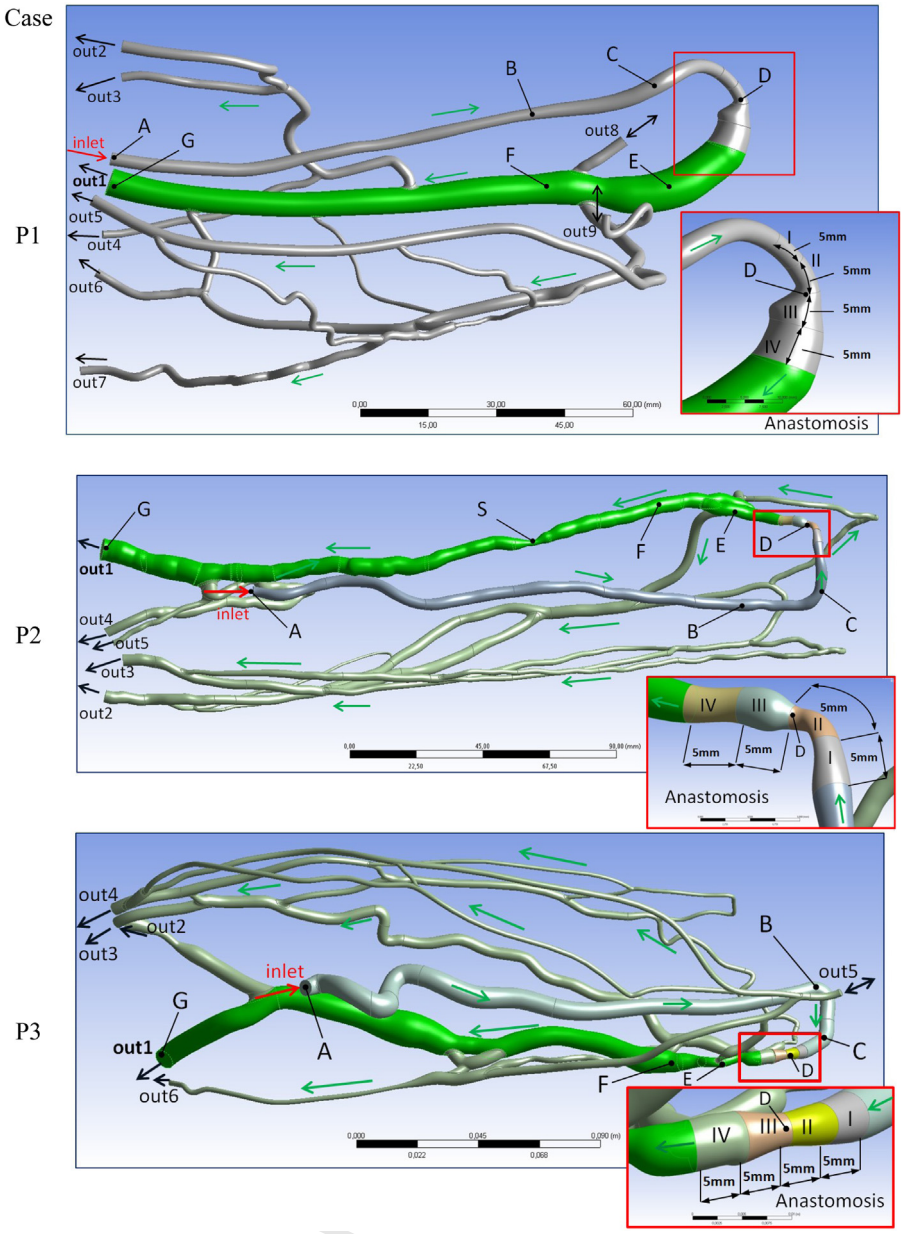

Fig. 1

described in our former papers [9,10]. The P2 Model was earlier presented in [9], however in this study, the non-stationary simulation was performed, which provides much more information on flow parameters and the WSS distribution.

2.2. *Mesh*

During the independence test, the number of prismatic sublayers in the vicinity of walls was increased keeping the same thickness of the boundary layer. The most dense unstructured numerical meshes built of tetrahedral elements inside the blood vessels and prismatic elements in the vicinity of walls, consisting of 6.67 million (Patient 1), 9.06 million (Patient 2), and 17.96 million (Patient 3) elements, were applied in simulations of the unsteady pulsating flow. The mesh convergence was assessed based on the grid convergence index (GCI) accordingly the method described in details by Celic et al. and used by Browne et al. in the study of flow in a simplified a-v fistula model [11,12]. The grid independence tests were conducted in each case with stationary simulations for peak-systolic flow conditions. The AAWSS and volume flow rate at the outlet cross-section were chosen parameters (ϕ) use for comparison of the meshes. The mesh parameters and the results obtained for the grids of different density in the models of Patients 1–3 are presented in Table 1. The whole procedure of the GCI test is described in the Supplementary materials (S0). The numerical uncertainty for fine grids for the AAWSS was 2.7%, 20.5%, 9.6%, and for the volume flow rate was lower and equal to 0.4%, 11.5%, and 0.2%, respectively for Patients 1–3.

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