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PRESSURE VARIATION IN REAL ARTERIOVENOUS FISTULA: EXPERIMENTAL STUDY

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Abstract. *Arteriovenous fistula (AVF), the surgical connection between an artery and a vein, is the most recommended vascular access (VA) for patients in hemodialysis treatment. Even though this type of access is well recommended, it can be affected by problems due to its construction and use. Studies show that pathophysiological problems are closely linked to flow conditions and vascular remodeling caused after the pressure short circuit due by the union between artery and vein. The present study sought to analyze the pressure conditions in vitro of an AVF, built from real data from a patient. To carry out the work, the following steps were performed: data acquisition and processing (computed tomography), manufacturing using 3D printing and experimental analysis. Values for the peak pressure at the entrance and exit of the AVF were 166.438 mmHg and 155.712 mmHg, respectively, showing a drop in the peak pressure of 10.726 mmHg, in addition to pressure values in specific regions consistent with the literature.*

Keywords: *Arteriovenous fistula, pressure variation, 3D printing.*

1. INTRODUCTION

Chronic kidney failure (CRF), an advanced stage of chronic kidney disease (CKD), is a disease characterized by severe and irreversible loss of kidney functions, making the patient need to undergo a therapeutic intervention (dialysis) to supply the body's physiological needs. In Brazil, according to a census by the Brazilian Society of Nephrology, in 2017 the estimated number of patients undergoing dialysis treatment in centers recognized by the Sistema Único de Saúde (SUS) was already over 120000 people (Thomé et al., 2017).

Hemodialysis, most common dialysis method (Thomé et al., 2017), is the form of dialysis treatment that performs extracorporeal blood filtration with the aid of filters. This process requires an VA to perform the removal, filtering and return of blood to the patient, and the AVF is the most recommended access for this type of treatment (Akoh, 2009; Briones et al., 2010; De Villiers et al. , 2018; Javadzadegan et al., 2017) when compared to other types of access. However, the arteriovenous fistula presents high failure rates after its conception and during its use, according to Remuzzi and Bozzetto (2017) about 60% of AVFs do not reach the ideal state of use.

After the creation of the AVF, there is a variation in the pressure field, this variation being one of the important parameters with regard to maturation and pathological conditions of access.

These new pressure conditions of the vascular network cause a geometric remodeling of the vessels (Browne et al., 2015; Pylayeva-Gupta, 2011), and a possible thickening of the vascular wall (Botti et al., 2013). Remuzzi and Bozzetto (2017) show that the high hemodynamic pressure can neutralize the intraluminal pressure of the system, causing circumferential tensions in the wall of the AVF. This high pressure (hypertension) induces hypertrophy of the vascular wall in response, leading in extreme situations to the occlusion of blood flow.

We can also cite the pressure drop caused by flow instabilities in the anastomosis (place of union between artery and vein) as being a global factor linked to the hemodynamics of vascular access (Botti et al., 2013).

It is observed, then, that the correct analysis of pressure variation in the VA helps in predicting vascular remodeling in the short term and in the ability to maintain the patency of access in the long term, with pressure being one of the global parameters linked to the conditions of access, avoiding possible unnecessary surgical interventions and improving the quality of life of patients.

In this work, the pressure values in a pulsatile flow, in vitro, were analyzed in an AVF model manufactured from real data from a patient, in order to relate the vascular geometry with the pressure variation in the VA.

2. METHODOLOGY

2.1 Data acquisition and processing

The medical images were obtained through computed tomography (CT), performed at the Hospital Universitário Onofre Lopes - HUOL (UFRN), of a patient with brachiocephalic AVF in the left arm, aged 72 years. The DICOM (Digital Imaging and Communications in Medicine) files from CT were treated in the *InVesalius* software (CTI - Campinas), reconstructing the vascular region of the left arm (Fig. 1(a)) and extracting the virtual AVF from the reconstructed geometry (Fig. 1(b)).

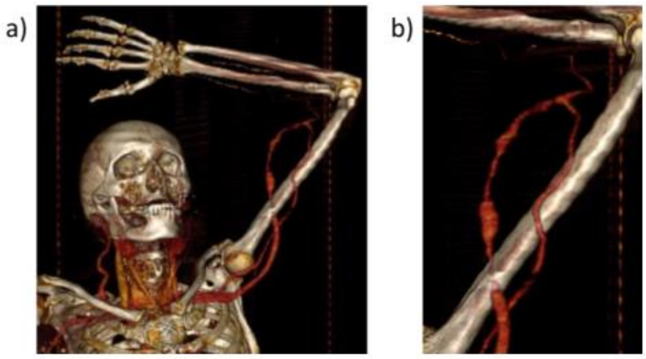

Figure 1. Three-dimensional reconstruction of the AVF.

The obtained AVF went through a process of improvement and superficial treatment, in order to correct discontinuities and smooth the mesh surface, improving the finish and facilitating the model manufacturing process for the experimental procedure.

2.2 AVF manufacturing

After the AVF geometry reconstruction and correction, the manufacturing process started. Access points were modeled in the AVF for pressure taps and extensions at the entrance (proximal artery), exit (proximal vein) of the VA and distal artery, keeping the cross-sectional area constant. The points for taking pressure were arranged as follows: two points in the arterial region, one point in the anastomosis region (union between artery and vein), two points in the venous region, located in pseudoaneurysms, one point at the entrance and one at exit, as shown in Fig. 2.

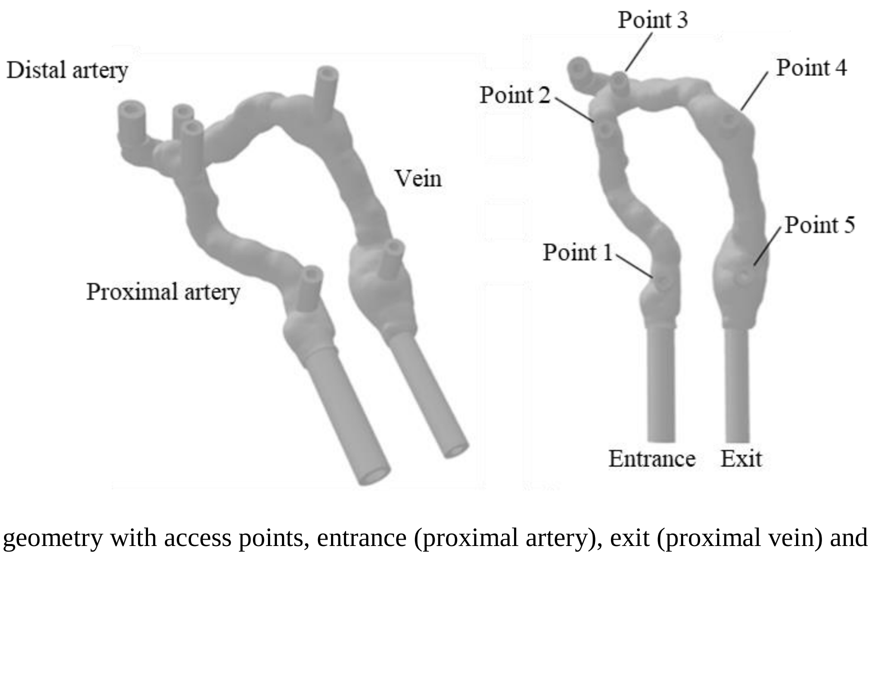

Figure 2. AVF geometry with access points, entrance (proximal artery), exit (proximal vein) and distal arterial.

2.3 Experimental procedure

The experimental test was performed on a systolic and diastolic pulse simulation bench (Fig. 3), with working fluid being water (μ = 1.002 mPa.s and ρ = 997 kg / m³). The experimental bench consists of a control, pumping and data acquisition system.

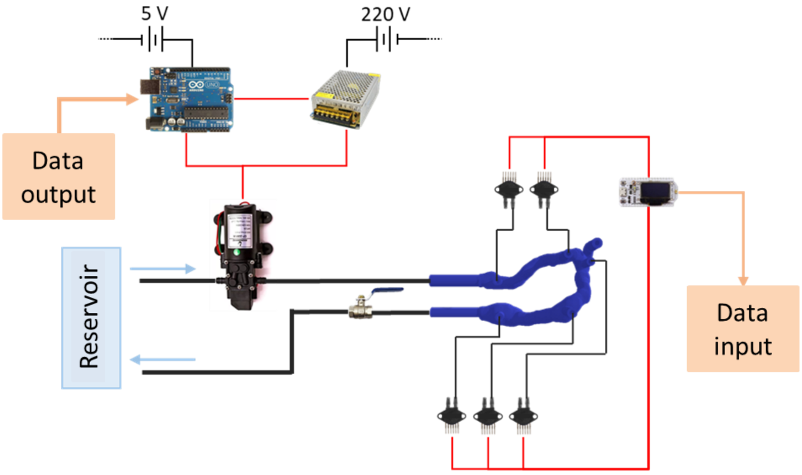

Figure 3. Experimental bench for systolic-diastolic pulse

The pressures at the pre-selected points were analyzed, correlating the results with the vascular geometry. From the pulse obtained from Sigovan et al. (2013) and implemented in the system, the values of pressure pulses were obtained at points (1), (2), (3), (4), (5), entrance and exit of the AVF, depending on the normalized time.

3. RESULTS AND DISCUSSION

After computational modeling and 3D printing, the AVF model for bench testing was obtained (Fig. 4). The AVF was manufactured directly from 3D printing, with ABS (*Acrilonitrila Butadieno Estireno*) as material, 0.1 mm resolution and 100% fill. Small leaks from the manufacturing processor were corrected by applying solvent to the surface of the printed AVF.

Figure 4. Arteriovenous fistula - 3D printing

The pressure pulses collected at points (1), (2), (3), (4) and (5) are observed in Fig. 5, where, in general, the systolic pressure peaks occurred at the normalized time of t / T = 0.3, at both points of the AVF.

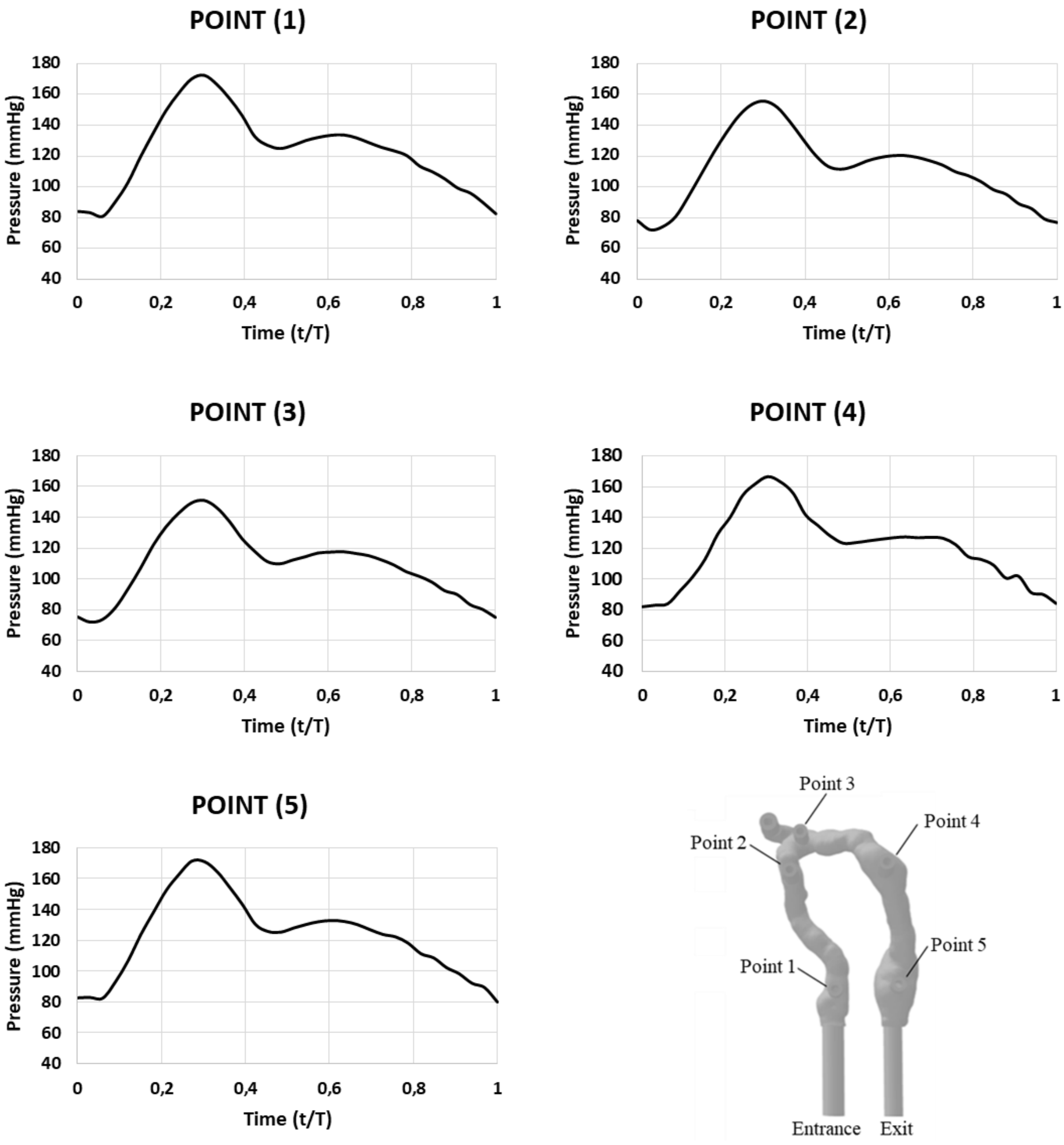

Figure 5. Pressure vs. Normalized time at points (1), (2), (3), (4) and (5)

The values for pressure peaks in the AVF are shown in Table 1. Based on the values presented and in Fig. 5 we can observe a significant difference between the pulses and pressure peaks related to the vascular region, the high peak values demonstrate that the stiffness of the vascular wall, given the manufacturing process of the AVF, induces high mechanical stresses on the surface of the vessels, resulting from the pressure value, in order to cause a possible change in the amount and organization of the tissues and structure that make up these blood vessels , as said by Junqueira and Carneiro (2013).

Table 1. Peak pressure values in the AVF

AVF Points	Pressure (mmHg)
Entrance	166.438 mmHg
Exit	155.712 mmHg
Point (1)	172,439 mmHg
Point (2)	155.637 mmHg
Point (3)	150.987 mmHg
Point (4)	166.513 mmHg
Point (5)	170.939 mmHg

The lowest pressure value, 150.987 mmHg, was observed at point (3), located centrally and in the upper plane of the anastomosis as shown in Fig. 2. This pressure data corroborates Botti et al. (2013), which relates the pressure drop in the anastomosis with flow instabilities and recirculation zones in this region. The anastomosis region is a region susceptible to recirculation and vortex formation, these flow structures causes a drop in global pressure, causing some problems such as intimal hyperplasia and atherosclerosis (Cunnane et al., 2017).

At points (4) and (5), regions of pseudoaneurysms resulting from venipuncture for treatment, high values for pressure in the AVF are observed. These high pressure values at the points can be explained by analyzing the area variation. After leaving the anastomosis, the flow tends to “organize”, and the variation in area is now a parameter for the drop or increase in pressure. At these points the area rises, decreasing the speed and, consequently, increasing the local pressure value.

Figure 6 shows the input and output pulses in the AVF, and you can see the difference in values with respect to pressure drop at the access.

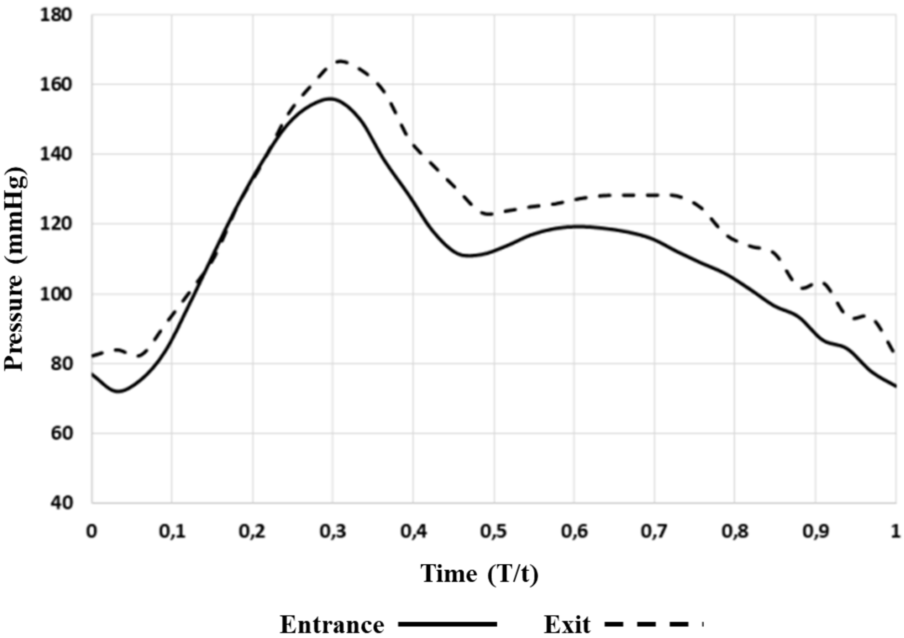

Figure 6. Pressure pulse (mmHg) vs. normalized time in the entrance and exit regions of the AVF

As shown in Tab. 1, the peak pressure values at the entrance and exit of the AVF were 166.438 mmHg and 155.712 mmHg, respectively, observing a drop in the peak pressure of 10.726 mmHg. The pressure drop value is less than 10% of the input value, evidenced by the VA wall's stiffness wall. It is expected in later analysis, with flexible models of AVF, an increase in pressure drop due to the damping of the flow due to the deformation of the vascular wall.

4. CONCLUSIONS

The analysis developed in this study made it evident that the variations in pressure in a pulsatile flow in arteriovenous fistulas are directly influenced by the geometry that make up this AV, showing the relationship between the values of local pressure and pressure drop during the flow. The pressure drop in the anastomosis region, for example, can be further explored when analyzing fistulas from other patients or even the material used to manufacture the VA for the test (stiffness).

The influence of this study is also very important in other flow parameters in arteriovenous fistulas, such as flow, shear stress, speed field, among others. These parameters can be used as predicates of access problems, effectively reducing or correcting them, improving the quality of life of patients with CKD and undergoing hemodialysis.

5. ACKNOWLEDGMENT

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7. RESPONSIBILITY NOTICE

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