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ANALYSIS OF PRESSURE DROP IN ARTERIOVENOUS FISTULA WITH VARIATION OF THE ANGLE OF ANASTOMOSE – IN VITRO STUDY

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Abstract. *The Arteriovenous Fistula (AVF) is a connection between an artery and a vein, made by a vascular surgeon for vascular access (AV) in people undergoing hemodialysis (HD). The construction of the AVF causes non-physiological conditions of blood flow, as a result of this it generates disturbances in the flow in the connection region, anastomosis. These disturbances such as recirculation zones, separation points and stagnation points are associated with the development of pathologies that cause stenosis, compromising or even canceling the use of the AVF as a VA. The Angle of Anastomosis (AA) is one of the geometric parameters that influence the intensity of perturbations in the anastomosis. Using the Fused Deposition Modeling (FDM) technique, in vitro models of the AVF were manufactured by 3D printing with 30°, 90° and 150° AA. An experimental workbench was used to provide the pulsatile flow. Pressures at the inlet and outlet of the AVF were collected using MPU5050DP pressure transducers. The results show that the upstream pressure decreases with the increase of AA and the downstream pressure increases, consequently the pressure differential decreases with the increase of AA, from 12 kPa at 30° AA to 3.1 kPa at 150 AA °. Therefore, the energy dissipated during the flow decreases in the anastomosis with the increase in AA. From the results obtained, it can be concluded that the AA influences the pressure between the region upstream and downstream of the anastomosis. The smaller the AA, the greater the pressure difference and the greater the energy dissipated in the anastomosis. In this context, it was estimated that the 150 ° AA is more favorable for the construction of the AVF because they present less changes in the system pressure, less energy dissipated in the anastomosis and, consequently, lower levels of disturbances in the flow.*

Keywords: *Arteriovenous Fistula, Angle of Anastomose, Pressure Drop*

1. INTRODUCTION

Arteriovenous fistula (AVF) is a connection between an arterial vessel and a peripheral venous surgically produced by a surgeon. This technique is used to perform a Vascular Access (VA) in patients affected by chronic kidney disease (CKD) and need to undergo replacement treatment by hemodialysis (HD). The AVF is preferentially chosen because it has advantages over other types of AV such as: central venous catheter and by graft, among the main advantages the use of the AVF stands out for having no penetrating tubes and catheters on the body surface, normal use of the arm outside of HD sessions, low risk of infection, simple and fast access to blood circulation and also for having low cost (Amato 2019; Gill et al. 2017).

Although the AVF is preferentially used among the types of VA, some risk factors can maximize the occurrence of stenotic pathologies which, in turn, can cause failure of the AVF as a VA (Rezapour et al. 2018). Among the most common complications in AVF, those that cause stenosis in the vessels represent a high incidence ranging from 17% to 42% in constructed AVF that may appear soon after surgery (Stolic 2013). Over the years, studies have investigated the predominance in localization of stenosis formation to secondary recirculating flow patterns (S. Sivanesan et al. 1999; Sharmila Sivanesan, How, and Bakran 1998, 1999). Several other, more recent studies using hemodynamic analysis by Computational Fluid Dynamics corroborate these results, that is, associating the predominance in the location of stenosis formation in regions that present a recirculating secondary flow pattern, mainly in the external wall of the vein near the proximal anastomotic junction and in the arterial segment in the region opposite anastomosis (Browne et al. 2014; Ene-Iordache and Remuzzi 2012; Javadzadegan et al. 2017).

One way to investigate the instabilities and intensity of flow disturbances imposed by the AVF construction is to verify the pressure drop between the arterial and venous segments. The smaller the pressure drop between the segments, the less flow energy is dissipated in the anastomosis by flow disturbances: such as separation points, recirculations and stagnation points, and consequently the lower the intensity of possible flow disturbances in the anastomosis (Grus et al. 2016; Okoye, Rajabi-Jaghargh, and Banerjee 2013; Silva, Karam-Filho, and Borges 2015).

With the purpose of contributing to the study of the relationships between hemodynamic factors and geometric variations in AVF, this work aims to visualize the effects of hemodynamics in AVF, energy dissipation with variation in the Angle of Anastomosis (AA).

2. METHODOLOGY

The AVF was modeled adapting a dimension of the Brachiocephalic type, with 4 mm in diameter in the artery and 6 mm in diameter in the venous segment. The Angle of Anastomosis (AA) was defined between the angulation of the arterial segment and the straight segment that represents the tangent at the idealized point of connection. Three AVFs were modeled with 30 °, 45 ° and 90 ° AA. The same anastomotic area was defined with an anastomotic length of 6 mm and 4 mm in width. The FAV drawings were made using *Autodesk Fusion® 360™ Software* and converted and exported in Standard Triangle Language (STL) format. Figure 1 shows a schematic image with the particularities of the idealized AVF used in this work.

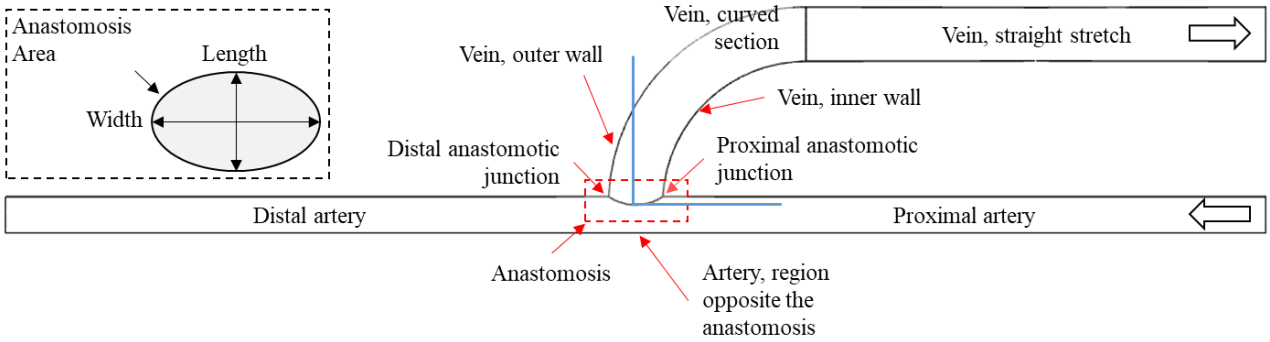

Figure 1. Schematic drawing of the FAV modeling.

Based on the FAV modeling, a 2 mm thick shell was drawn around it. To acquire the pressure downstream and upstream of the anastomosis, two Pressure Taps (PT) were installed perpendicular to the proximal artery (PT1) and at the exit of the venous segment (PT2). The in vitro AVF was manufactured in successive layers with 100% filling by 3D printing using the Fused Deposition Modeling (FDM) technique, made by extrusion in a filament by thermoplastic material consisting of Acrylonitrile Butadiene Styrene (ABS). In Figure 2, a schematic image with the main components used in the experimental workbench and the assembled experimental circuit is presented.

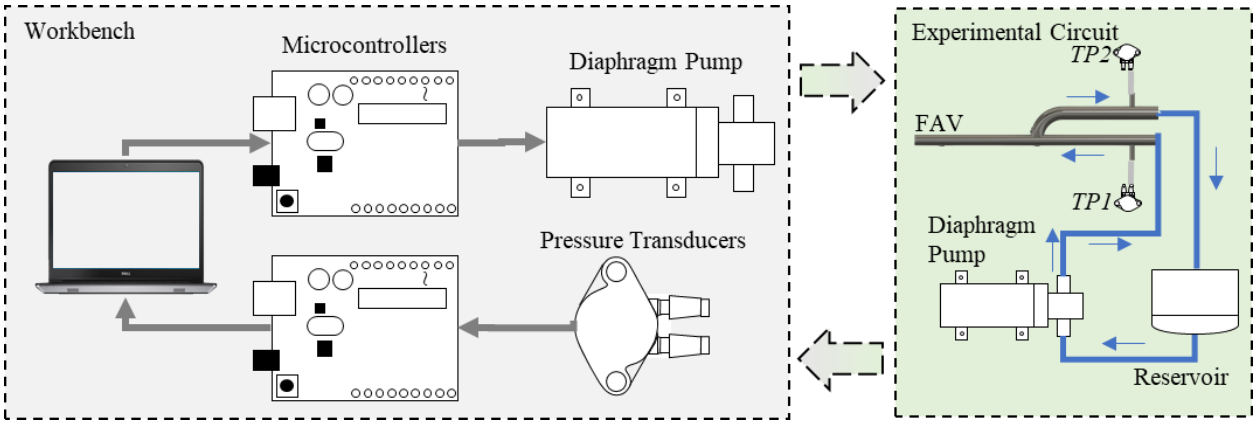

Figure 2. Schematic design of the experimental workbench and the experimental circuit.

To provide the pulsatile flow, an experimental workbench manufactured at the laboratory of fluid mechanics (LFM) of the Federal University of Rio Grande do Norte (UFRN) was used, capable of simulating the arterial pulse equivalent

to that found in the brachiocephalic AVF. The experimental workbench uses a microcontroller capable of controlling the flow in the AVF by altering the voltage applied to the diaphragm pump and two microcontrollers to acquire the flow parameters in the AVF. Two MPU5050DP pressure transducers were used to acquire the pressure in PT1 and PT2. In this work, the distal artery was considered blocked, with the flow entering through the proximal artery, passing through the anastomosis and exiting through the distal artery. The circuit was interconnected by connections, valves and conduits.

Two codes were developed for motor control and pressure data acquisition, the codes were programmed in c/c++, compilers and implemented in the respective microcontrollers. The *TelemetryViewer Software* was used for monitoring, synchronization and acquisition of pressure data, and the *Microsoft® Excel® Software* was used to process and graph the results for each AVF. The pressure pulses were normalized over time and the maximum, minimum and average pressure parameters were calculated. Data for AVF wifh 90 ° AA were adopted for comparison purposes.

3. RESULTS AND DISCUSSION

Pressure data were collected at the PT1 and PT2 pressure taps. Figure 3 shows the pressure-by-time graphs of the pulsatile flow in in vitro AVF for the 30°, 90° and 150° AA.

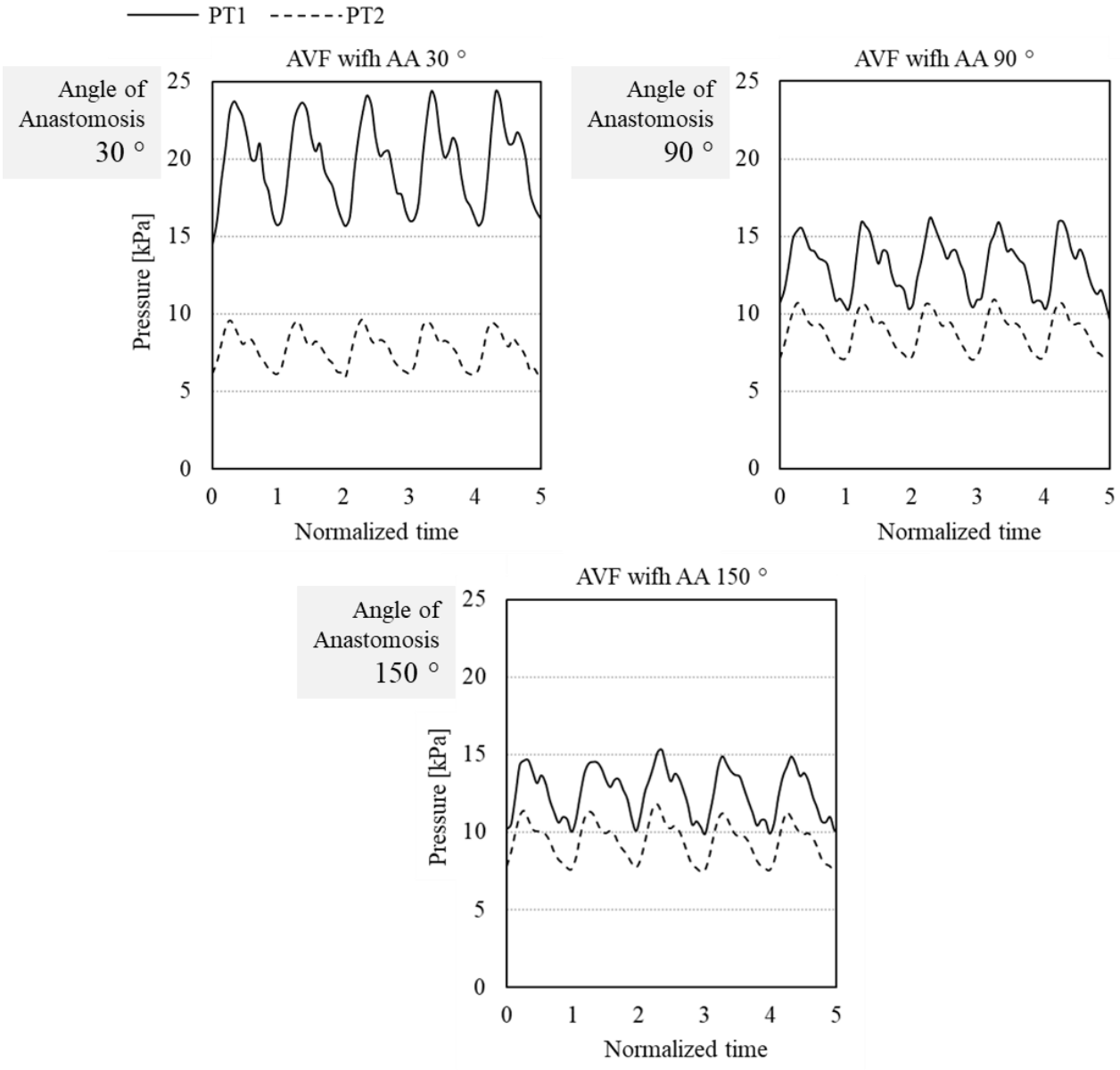

Figure 3. Graph of pressure versus time normalized in PT1 and PT2 for pulsatile flow.

The pressure pulses obtained during the experiment in the AVF with 30 ° AA are observed, presenting values in PT1 with maximum pressure of 24.39 kPa (182.94 mmHg), minimum of 14.49 kPa (108.68 mmHg) and mean pressure of

19.72 kPa (147.91 mmHg). In PT2 with a maximum pressure of 9.64 kPa (72.31 mmHg), a minimum of 5.94 kPa (44.55 mmHg) and an average pressure of 7.72 kPa (57.90 mmHg).

The pressure pulses obtained during the experiment are observed in the AVF with AA of 90 °, with values in PT1 with a maximum pressure of 16.17 kPa (121.29 mmHg), minimum of 10.50 kPa (78.76 mmHg) and mean pressure of 13.07 kPa (98.03 mmHg). In PT2 with a maximum pressure of 11.11 kPa (83.33 mmHg), a minimum of 6.83 kPa (51.23 mmHg) and an average pressure of 8.84 kPa (66.31 mmHg).

The pressure pulses obtained during the experiment are observed in the AVF with AA of 150 °, with values in PT1 with a maximum pressure of 15.30 kPa (114.76 mmHg), minimum of 9.87 kPa (74.03 mmHg) and mean pressure of 12.49 kPa (93.68 mmHg). In PT2 with a maximum pressure of 11.99 kPa (89.93 mmHg), a minimum of 7.25 kPa (54.38 mmHg) and an average pressure of 9.43 kPa (70.73 mmHg). It can be noticed a decreasing behavior in the pressure parameters in PT1 as a function of the increase in AA, which is distinguished from the behavior in the pressure parameters in PT2 where it is possible to notice an increasing behavior as a function of the increase in AA.

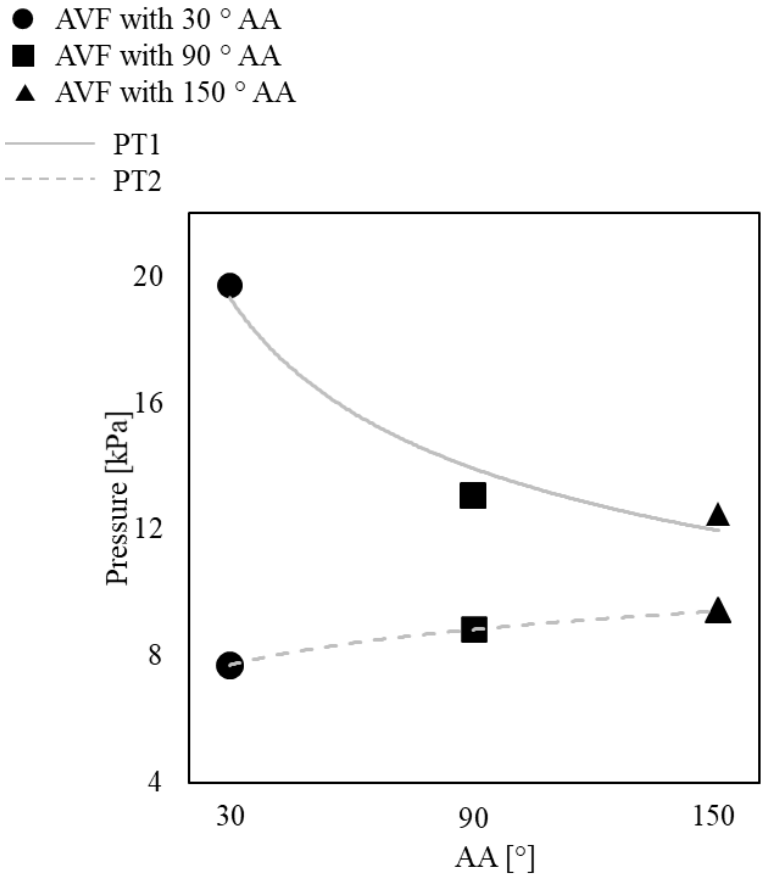

Figure 4. Graph of pressure versus AA in PT1 and PT2.

The maximum variation in the mean pressure in relation to the 90° AA was 50.84% higher for the 30° AA and –9.21% lower for the 150° AA. On the other hand, in PT2, the pressure is noted, with an opposite behavior with an increasing trend. The maximum variation in mean pressure in relation to the 90° AA was -12.66 % smaller for the 30° AA and 9.08% larger for the 150° AA. These same behaviors extend to the maximum and minimum pressures in PT1 and PT2. Under the conditions adopted in this work, this behavior demonstrates that the pressures upstream of the anastomosis are more sensitive for AA lower than 90 °, with higher values in the pressure parameters at increasing rates the lower the AA. The results of pressures in PT1 and PT2 demonstrate pressurization of the system upstream to the anastomosis and slightly depressurized downstream in AA of 30°. The difference between the pressures ΔP (PT1-PT2) determines the total resistance to flow in the system. To quantify the total resistance, ΔP (PT1-PT2) was calculated for each AA.

In Figure 5, the results for ΔP (PT1-PT2) can be seen as a function of AA.

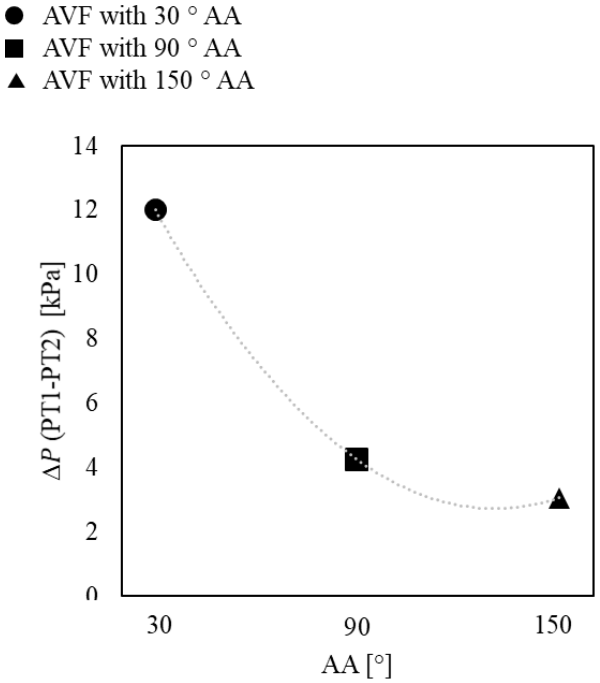

Figure 5. Graph of pressure drop versus AA.

The pressure differential ΔP (PT1-PT2) decreased with increasing AA. Values decreased from 12.0 kPa (90 mmHg) at 30° to 3.1 kPa (23.25 mmHg) at 150°. These pressure differences are similar to those found in other works with AVF. Second ENE-IORDACHE et al. (2013), demonstrated that the pressure drop decreased by 43%, going from 14.75 mmHg to 6.4 mmHg by increasing the AA from 30° to 90° in AVF. In HASSAN et al. (2012), studied the pressure drop in different AVF AA to investigate the effect of pressure, pointing out a decrease in pressure drop with the increase in AA, stabilizing the pressure drop around 75°. Thus, these results corroborate the literature, pointing out a significant influence of AA to establish the degree of resistance to flow in FAV. Therefore, controlling the AVF AA seems to be opportune to determine the energy dissipation through the pressure drop, which may mean lower intensities in the anastomotic disturbances, with a lower incidence of stenosis formation in the AVF.

4. CONCLUSION

This work demonstrated that AA influences the energy associated with flow in the AVF, under the conditions adopted in this work. For AVF with 30° AA, there is the presence of upstream pressurization and downstream depressurization, resulting in an expressive pressure differential and consequently higher energy dissipated during the flow. Thus, the in vitro AVF with AA of 150 ° provide lower values in the pressure differential, consequently lower energy losses. Future experiments should be carried out, such as the study of pressure drop at other angles to map the behavior of energy dissipation, as well as to better understand and account for energy dissipated, specifically in the anastomosis. In future studies we will implement working fluid with a viscous characteristic that simulates blood fluid.

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