SBC2013-14408

EFFECT OF ANASTOMOTIC ANGLE ON PRESSURE DROP IN ARTERIOVENOUS FISTULAE

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ABSTRACT

The amount of the blood flow rate to an arteriovenous fistula (AVF) is one of the primary factors that determine the likelihood of maturation. The increase in the flow rate is dependent on the amount of the resistive forces in the AVF which can be evaluated by pressure drop (Δp). Our group has shown that the surgical configuration of AVF affects the hemodynamics and thus the remodeling within the AVF. Here, our *aim* is to study the effect of AVF configuration on the induced Δp. Based on the data collected in our previous *in-vivo* porcine experiments, idealized models of AVFs with anastomosis angles of 30°, 60°, and 90° were created and numerically solved to find Δp under steady-state conditions. The Δp from the idealized models were within the same range as the experimental data (15.31 ± 3.78 mmHg). The highest and lowest Δp were found to be 14.75 and 6.40 mmHg for the 30° and 90° AVFs, respectively. Moreover, an inverse relationship was found between the Dean number (*De*) and Δp. As *De* decreased with increasing radius of curvature (from higher anastomotic angles to the lower), the Δp increased. These data suggest that creating the AVFs in a surgical configuration that results in larger *De* (lower radius of curvature such as 90° AVF) may achieve higher flow rate due to relatively lower Δp. In contrast, creation of AVF with lower *De* which represents a sharp bend with high radius of curvature (30° AVF) could be detrimental to AVF maturation as it results in relatively higher Δp.

INTRODUCTION

AVFs are the preferred method of vascular access for hemodialysis due to their higher patency rate and lower infection rate than A-V grafts. However, 28 to 53 percent of AVFs fail due to their inability to mature and supply adequate blood flow for hemodialysis. In order for an AVF to be considered mature, blood flow levels must reach 600 ml/min which is a multi-fold increase from the normal flow values of 60-120 ml/min in the forearm [1]. The increase in the blood flow rate is dependent on the amount of the resistive forces along the bend which can be related to vasodilation/constriction of the vessels over time [2, 3]. Pressure drop along the AVF can be used to derive information about the amount of the resistive forces to the flow, and thus can be used as a measure for the assessment of maturation-status of AVFs. Here, our *hypothesis* is that the surgical configuration of the AVF has a significant effect on the amount of the pressure drop along the fistula. In this study our *aim* is to compare the pressure drop values in three different cases of an AVF model, in which the angle of anastomosis varies between 30, 60, and 90 degrees.
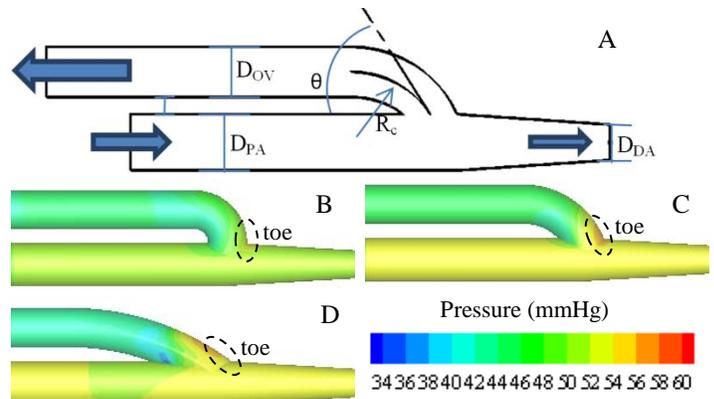

Figure 1. A: Schematic of the AVF model in which ϴ is the anastomotic angle and R_c is the radius of curvature; and Pressure contours along the AVF for the B: 90°; C: 60°; and D: 30° AVF.

METHOD

Data collected at 2 days post-surgery on our previous *in-vivo* porcine AVF model [3] was used to find the average dimensions and flow rates for the arterial and venous segments. The schematic of the AVF geometry which is comprised of the proximal (PA) and distal (DA) arteries, and also the outflow vein (OV) is shown in Figure 1A. The diameters of the PA, DA, OV, and also the distance between the vein and the artery (L_0) are 6.5, 4.1, 5.8, and 2 mm, respectively. Using these dimensions, AVFs were created in 90°, 60°, and 30° anastomotic angles with corresponding radii of curvature (R_c) of 4.9, 9.8 and 36.5 mm, respectively. The boundary conditions for the numerical analysis were selected to mimic the averaged condition under steady state assumption in the pig experiment. Specified were the parabolic velocity profiles at the PA inlet with the flow rate of 1474 ml/min and also fully-developed velocity profile at the DA outlet with the flow rate of 346 ml/min. The Reynolds numbers at these boundaries were 1464 and 508, respectively. Also, an outflow condition was specified at the OV outlet. In order to minimize the effect of boundary conditions on the AVF, all the boundaries were extended using straight pipes with the length of 20D; where D is the diameter at the corresponding boundary. The numerical domain was solved using the control volume techniques to obtain the flow field within the AVFs.

RESULTS

Figures 1B-D show the pressure contours along the AVF wall for the three cases. Pressure values at each node were obtained according to a reference pressure value of 53 mmHg at the PA inlet, which represented the average pressure obtained at the PA inlet from our porcine experiment [2]. In all the cases, the maximum pressure occurred at the anastomotic toe (indicated on figure). Pressure values were higher along the outer wall, while relatively lower levels of pressure were found in the inner wall. Moreover, Table 1 shows that the total pressure drops (Δp) from the AVF models considered in this study fall within the range of the data collected in our porcine experiment (15.31 ± 3.78 mmHg). The total Δp was calculated from the PA inlet to a cross-section that was located $5D_{PA}$ away from the anastomotic junction along the OV.

Table 1. The total Δp for the AVFs with different anastomotic angles along with the total Δp from the porcine model.

	$\Theta = 30°$	$\Theta = 60°$	$\Theta = 90°$	Porcine Model
Δp (mmHg)	14.75	7.91	6.40	15.31 ± 3.78

The Δp along the centerline of the venous segment within the anastomotic region is shown in Figure 2. The Δp at each centerline node was calculated as the difference between the corresponding centerline pressure and the pressure at the PA inlet. In general, as the flow accelerated inside the bend region, the Δp also increased to a
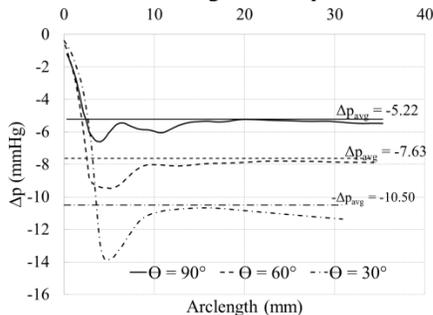
Figure 2. Pressure drop along the centerline of the venous segment within the anastomotic region.

maximum value which followed by a decrease in the Δp towards the outer bend. However, as the flow exited the bend segment and started to recover its fully developed profile, the Δp began to increase slightly again. The maximum Δp (associated with the largest decrease in the Δp variation in Figure 2) within the anastomosis was the greatest in the 30° AVF (13.85 mmHg), while it was 9.40 and 6.54 mmHg for the 60° and 90° cases, respectively. Similarly, the average Δp over the anastomotic region was highest for the 30° AVF (= 10.50 mmHg), while it was 7.63 and 5.21 mmHg for the 60° and 90° cases, respectively.
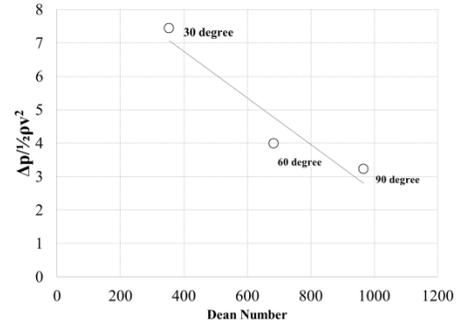
Figure 3. Pressure drop plotted against Dean number.

From the fluid dynamics prospective, flow in bends can be categorized using Dean number ($De = \sqrt{\frac{D_{ov}}{2R_c}} Re_{ov}$; where R_c, D_{ov} and Re_{ov} represent the radius of curvature of the anastomosis, diameter of the OV and the average Reynolds number in the OV, respectively). De determines the strength of the secondary vortices in the bend which also affects the shape of the velocity profiles. Since the average Re for all the cases is the same, the value of De only changed with the R_c, and had the values of 354, 683, and 966 for the 30°, 60°, and 90° AVFs. Figure 3 shows the variation of the total Δp normalized with the dynamic pressure of the OV ($\Delta p_n = \Delta p / 0.5\rho \overline{v_{ov}}^2$) with respect to the De, corresponding to each AVF. A significant inverse relationship was found between the De and Δp_n. That is, the AVFs with higher De had lower Δp_n and vice versa.

DISCUSSION AND CONCLUSION

In this study, effects of the surgical configuration of the AVF on the pressure drop along the access were investigated. It was shown that by reducing the anastomotic angle of the AVF from the 90° to 30°, the induced Δp can increase for almost two fold. Moreover, we showed that the geometrical features of the AVF can be linked to the Dean number which showed an inverse correlation with the Δp. Therefore, creating the AVFs in a surgical configuration with low De, which represented a sharp bend with large radius of curvature such as 30° AVF, can induce relatively high Δp, and thus larger resistive forces. This can be detrimental to the increase in the blood flow rate to the access and thus can have adverse effect on the AVF maturation.

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