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A LONGITUDINAL ASSESSMENT OF WALL SHEAR STRESS VARIATION ON ARTERIOVENOUS FISTULA MATURATION

Ehsan Rajabi Jaghargh[1], Prabir Roy-Chaudhury[2], Paul Succop[3], Rupak K Banerjee[1]

[1]Mechanical Engineering Program, School of Dynamic Systems, University of Cincinnati, Cincinnati, OH

[2]Cincinnati Dialysis Access Research Program, Division of Nephrology, University of Cincinnati, Cincinnati, OH

[3]Department of Epidemiology and Biostatistics, University of Cincinnati, Cincinnati, OH

ABSTRACT

Arteriovenous (AV) fistula is the most preferred form of vascular access for end-stage renal disease patients. Acute changes in hemodynamics and in particular wall shear stress (WSS) immediately after fistula placement are followed by the dilation of the vasculature luminal area to recover the normal physiological condition before surgery. However, vasodilation in AV fistula is not well understood and thus, the major goal of this study is to assess the longitudinal effect of wall shear stress on fistula maturation. Six AV fistulae with curved (n = 3) and straight (n = 3) configurations are created between the femoral artery and vein of three Yorkshire pigs. Anatomical configuration and flow measurements are performed at 2D (D: days), 7D, and 28D post-surgery. It is shown that fistulae with relatively higher baseline axial WSS may result in better maturation as compared to the ones with lower levels of baseline axial WSS. This finding is novel and hasn't been reported in previous studies. Moreover, it is found that the longitudinal variation of WSS is also of high importance in prediction of the maturation of AV fistula. *Fistulae whose mean axial WSS decreases over time achieve larger mean area, and therefore, favorable remodeling, while an increasing trend of axial WSS is detrimental to fistulae maturation.* Also, it is found that curved fistula as compared to the straight configuration results in larger luminal area over time and thus, is the preferred form of AV fistula.

INTRODUCTION

Arteriovenous (AV) fistula is currently the preferred mode of vascular access as it has lower infection, thrombosis, and stenosis rate compared to other forms of hemodialysis access such as PTFE grafts. AV fistulae mostly fail either due to a primary non-function known as failure to mature or later venous stenosis. Primary non-function is shown to be associated with aggressive neointimal hyperplasia. Reasons for non-maturation are not clearly understood; however, hemodynamic factors, especially spatial and temporal patterns of wall shear stress (WSS) are believed to have significant effect on venous remodeling [1]. In this regard, anatomical configuration of AV fistula is of great importance as it alters the WSS patterns [2]. Moreover, vasodilation occurs due to the adoptive response of vessels to the rapid changes in hemodynamics immediately after placement of fistula to maintain the WSS levels within the normal range [1]. However, there is lack of information regarding the relation between early WSS patterns and the associated adoptive response in the context of AV fistula. Therefore, the primary goal of this study is to assess the effect of baseline WSS (initial days post-surgery) on maturation of fistula at subsequent time points.

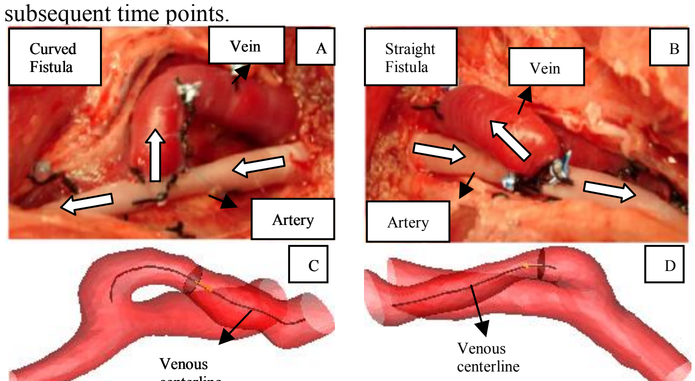

Figure 1. Actual and reconstructed geometry of curved (A, C) and straight (B, D) fistula. White arrows show the flow direction.

METHODS

Two fistulae with curved and straight configurations (Fig 1) are created between the femoral artery and vein, on either limb of a pig. Three pigs are considered in this study and a total of 6 fistulae (three curved and three straight) are created. Pigs are sacrificed at 7D (D: days) [one pig] and 28D (two pigs) post-surgery. Flow and internal diameter measurements are performed at 2D, 7D, and 28D after placement of fistula. Details regarding the pig experiment, methods, measurements, and CFD model are explained in our previous studies [3] and are not repeated here.

Once the solution for flow field is obtained, 20 cross-sections (1 mm in between) are created normal to the centerline of the venous segment in both curved and straight fistulae, as shown in Figs. 1C and 1D, respectively. The mean WSS vectors at each cross-section are obtained by averaging WSS over the cardiac cycle and subsequently, their dot products with the corresponding unit normal vector result in mean axial WSS. In the entire paper the axial WSS is referred to as WSS.

RESULTS

Geometry and flow field in six fistulae with curved (n = 3) and straight (n = 3) configurations are obtained at three time points (2D, 7D, and 28D). Mean WSS and area are calculated from the CFD analysis. Data obtained at 2D are referred to as baseline data.

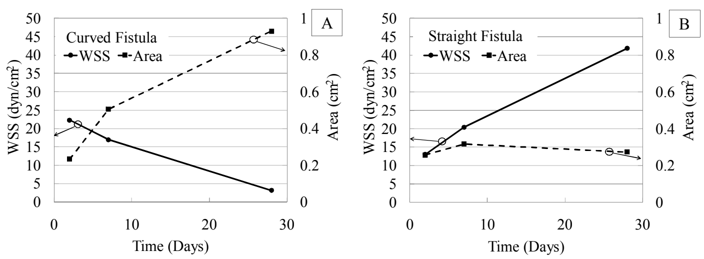

Figure 2. Variations of mean axial wall shear stress (WSS) and mean area along the venous segment of the fistula at different time points for (A) curved and (B) straight fistulae.

Variations of mean axial WSS and mean area along the venous segment of curved and straight fistulae at different time points are shown in Figs 2A and 2B, respectively. Mean WSS and mean area for a specific configuration are obtained by averaging their corresponding values over the 20 cross-sections created along the venous segment. It is observed that WSS in curved fistula decreases from 22.29 dyn/cm^2 at 2D to 3.17 dyn/cm^2 at 28D, while increasing from 13.02 dyn/cm^2 at 2D to 41.83 dyn/cm^2 at 28D in the straight configuration. The decreasing trend of WSS in curved fistula is accompanied with increase in mean area from baseline (= 0.23 cm^2) to 28D (= 0.93 cm^2). However, the increasing trend of WSS in straight fistula coincides with almost unchanged luminal area over time (from 0.26 cm^2 at 2D to 0.27 cm^2 at 28D). The proximity of the baseline mean area in curved (= 0.23 cm^2) and straight (= 0.26 cm^2) fistulae suggests that this parameter should not be considered as a factor for prediction of the fistula maturation. However, comparison between the baseline values of WSS in the curved (= 22.9 dyn/cm^2) and straight (= 13.02 dyn/cm^2) configurations reveals that relatively higher WSS at baseline may result in better maturation in later time points.

Although baseline WSS may be an initial indicator of the ability of fistula to mature, variation of the difference of WSS from the WSS baseline values over time might be of higher importance in the prediction of fistula maturation. To assess this effect, variation of the difference from the corresponding baseline values of mean WSS (ΔWSS) and mean area (ΔArea) is studied at 7D and 28D (Fig 3). ΔWSS at 7D for curved fistula (= 0.96 dyn/cm^2) is much lower than the one for the straight configuration (= 7.40 dyn/cm^2), which results in larger area difference in curved fistula (= 0.24 cm^2) as compared to the straight configuration (0.06 cm^2). Further, at 28D ΔWSS for curved fistula is negative (= -19.11 dyn/cm^2); showing considerable reduction in WSS at 28D with respect to the baseline, while the straight configuration has a high positive ΔWSS (= 23.98 dyn/cm^2) which reveals a substantial increase in WSS from 28D as compared to 2D. Associated with these ΔWSS values, ΔArea for curved and straight fistula at 28D are 0.68 and 0.05 cm^2, respectively. This shows that for a favorable remodeling in a fistula, reduction in WSS is needed. This finding is consistent with the adoptive response of vasculature to dilate in response to the increased level of WSS post-surgery to recover the pre-surgery WSS levels.

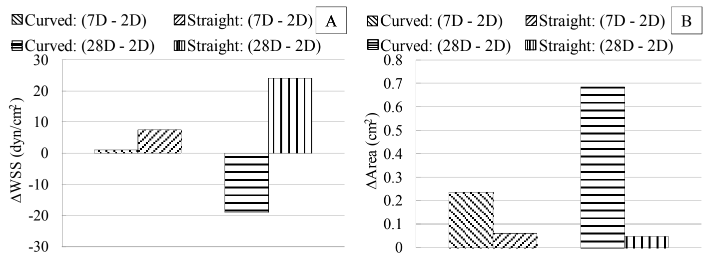

Figure 3. Difference of mean axial WSS (WSS) and difference of mean area at 7D or 28D post-surgery from the corresponding mean WSS and mean area at 2D, respectively, for (A) curved, and (B) straight fistulae.

CONCLUSIONS

This study shows that the levels of axial WSS in baseline and its variation over time are two factors that can predict the ability of a fistula to mature. It is shown that the baseline WSS may provide an initial assessment of fistula maturation in the sense that a fistula with comparatively higher baseline WSS may achieve larger luminal area as compared to the one with lower baseline WSS levels. However, studying the difference of WSS with respect to its baseline WSS over time can provide complementary information regarding the AV fistula maturation. Fistulae with decreasing WSS over time achieve larger luminal area, while the increasing trend of WSS is shown to be detrimental to vasodilation. It is also noteworthy that as compared to the straight configuration, curved fistula results in more desirable maturation, and therefore, may be considered as the preferred configuration for native dialysis accesses.

ACKNOWLEDGEMENTS

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