ON THE EXISTENCE OF AN OPTIMUM END-TO-SIDE GRAFT/ARTERY JUNCTION GEOMETRY

Michael Walsh (1), Thomas O'Brien (1), Tim McGloughlin (1), Pierce Grace (1,2)

Biomedical Engineering Research Centre, Mechanical and Aeronautical Engineering Department, University of Limerick, Limerick, Ireland

Regional Hospital, Dooradoyle, Limerick

INTRODUCTION

Intimal hyperplasia causing stenosis at the distal anastomosis is a major cause of failure of vascular bypass grafts [1, 2]. Anastomotic restenoses occur predominantly at the heel and toe of the anastomosis and on the artery bed, opposite the anastomosis [3]. Disease formation at the suture line can be attributed to three major factors, namely surgical injury, material mismatch and the abnormal flow patterns around the anastomosis. However, disease formation on the bed of the junction is thought to be entirely due to the abnormal flow patterns created as the blood flows from the graft into the artery, impinging on the bed of the junction. Such flow behaviour is unphysiological, as end to side junctions do not occur naturally. Thus, hemodynamic flow patterns in distal end-to-side anastomoses are widely implicated in the initiation of the disease formation process [4].

It is known that flow patterns created by end-to-side distal anastomoses exert abnormal wall shear stress (WSS) distributions on the endothelial cells on the bed of the junction [5]. The role of wall shear stress (WSS) in intimal thickening has been the subject of much debate with high WSS, low WSS, WSS gradient and oscillating WSS theories all being proposed as aetiological factors for anastomotic intimal thickening. These theories have been supported by experimental findings and it is possible that each theory has a role to play in the restenosis process.

It is thought that vein cuffs or patches may improve anastomotic junctional hemodynamics by decelerating the flow, thereby reducing peak WSS and relaxing WSS gradients. As a result it is commonly perceived that an optimum graft/artery junction geometry may exist. This study used computational fluid dynamics (CFD) to analyse the flow patterns associated with specific graft/artery junction geometries in three dimensional models.

MATERIALS AND METHODS

Flow patterns within end-to-side anastomosis configurations were simulated using a commercially available computational fluid dynamics (CFD) package (Fluent Europe). Three-dimensional models were developed using ProEngineer (Parametric Technology Company) and subsequently exported into Geomesh for grid generation. Numerical simulations used a non-Newtonian fluid model and time-dependent in-flow boundary conditions. Rigid walls and zero flow in the proximal outflow segment were assumed. The resting pulse used in this study is characteristic of a femoral artery pulse. This pulse had a frequency of 1Hz, a Womersley parameter of 4.2 and a maximum Reynold's number equal to 350. For the time-dependent flow models time step independence was established at 0.01s. The results are presented for both the peak velocity and the mean velocity in the decelerating phase of the pulse which occur at pulse times t = 0.14s and t = 0.26s respectively.

Idealised models were developed using two intersecting 6mm conduits at varying angles. The arterial section is 100mm long with the heel of the junction located 33mm from the end of the proximal outflow segment. The 'graft' is 50mm in length. The internal angle was varied from 15 to 60 degrees. The graft calibre was varied from 3 to 8mm internal diameter giving graft/artery diameter ratios of 0.5 to 1.33. The influence of the use of patches and cuffs in the junction area was investigated using a Taylor patch model with varying patch size and a Miller Cuff model with varying cuff height and graft angle.

RESULTS

The qualitative results for each of the models were similar. Recirculation regions were found opposite the heel and distal to the toe of the junction in all models. Flow impinged on the junction bed creating a bed stagnation point (BSP). As the flow moves distally through the distal outflow segment the momentum of the fluid causes it to follow the vessel wall curvature creating helical flow patterns. By allowing the flow to enter the host artery at a low angle in the force of the impinging flow on the artery bed is reduced. The influence of junction angle on peak WSS is illustrated in figure 1. Reducing the graft/artery angle also results in weaker heel recirculation, albeit through a larger region. There is reduced strength of the helical flow patterns associated with reduced graft/artery angle. Varying the graft/artery calibre demonstrated that having a graft calibre greater than that of the host artery helps to reduce the peak WSS magnitudes and gradients acting on the artery bed, see figure 2. In addition, the size of the flow separation region downstream from the toe is reduced when the graft has a larger diameter than that of the host artery. The quantitative results for the patch and cuff analyses are presented as normalised wall shear stress gradients in figures 3 and 4. While the Taylor patch does appear to provide beneficial hemodynamic effects, the disease influencing hemodynamic characteristics remain. However, it was found that the flow separation region distal to the toe can be eliminated by imposition of a Taylor patch. The results demonstrated that while the presence of a cuff can have significant effects on the quantitative results, again the general flow patterns through the junction remain the same. It was also evident from the results that cuff inclusion serves to divert the flow toward the bed, thus increasing the magnitudes of the WSS acting at the bed of the artery. However, at the mean velocity in the deceleration phase of the pulse a higher cuff enables further deceleration of the fluid through the junction thereby decreasing peak WSS magnitudes.

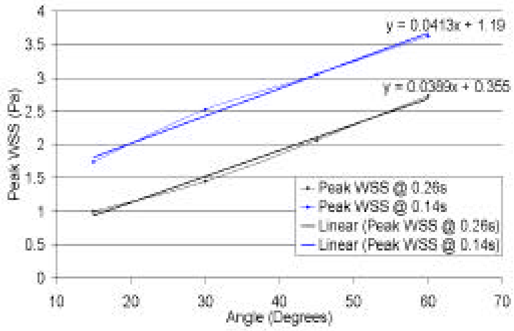

Figure 1 – Variance of peak WSS with graft/artery angle

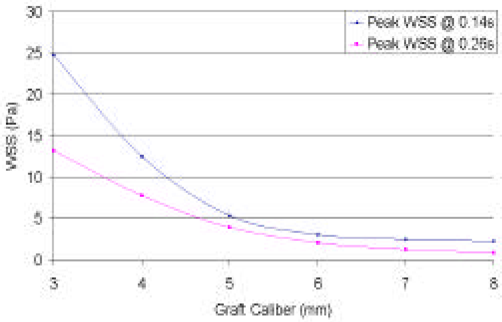

Figure 2 - Variance of peak WSS with graft calibre

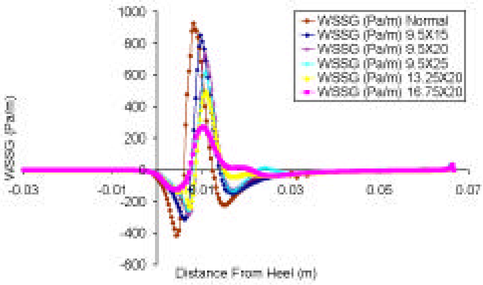

Figure 3 - WSSG at t=0.26 for the five patches of interest compared to the normal non-cuffed case

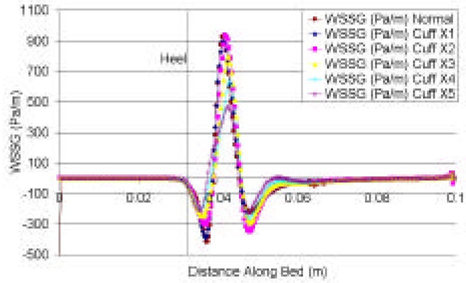

Figure 4 - WSSG at t=0.26 seconds for the five cuff heights and the normal non-cuffed case

DISCUSSION

The results demonstrate the effects of geometry on the location of the BSP, recirculation regions, helical flow patterns in the DOS and velocity profiles. The goal for optimising the graft/artery junction geometry can be reduced to the choice of reducing the peak values in the normalised WSSG distribution or reducing the area over which the normalised WSSG distribution has a non-zero value. However, which approach to take cannot be determined from the present study. A study to assess the response of endothelial cells to specific WSSG is required to provide insight into how the design of graft/artery junctions may be improved.

Based on the possible outcomes from such a study, the graft/artery junction can be designed to achieve “optimised” geometries. The Taylor patch and Miller cuff techniques have tried to achieve this. The Taylor patch surgical technique attempts to reduce the peak values of the normalised WSSG distributions while the Miller Cuff technique attempts to minimise the axial distance for which the normalised WSSG distribution has a zero value. Since both surgical techniques have only moderate patency rates [6, 7] it is concluded that an optimum end-to side graft/artery junction geometry, which would significantly increase the patency rates of peripheral bypass surgery, has yet to be determined.

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