Hemodynamic Interpretation of Various Extraanatomical Bypasses: Clinical & Engineering Views

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1. Introduction

Axillo-biFemoral (Ax-Fem) bypass as the extra-anatomical bypass has been well accepted for the management of aorto-iliac artery occlusive disease (AIOD). Ax-Fem bypass is still second best option for the AIOD when more physiological and anatomic Aorto-biFemoral (Ao-Fem) bypass cannot be implemented due to various risks, though its clinical results have not been as excellent as those of Ao-Fem bypass. Various types of configuration for the construction of Ax-Fem bypass, therefore, were proposed to improve its patency rate (Figure 1-5). But their clinical results have been mixed and the superiority of one type to the another has not been clearly proven yet. Hence, further hemodynamic study of various models of Ax-Fem bypass has been warranted for the selection of hemodynamically more advantageous type.

2. Purpose

In order to determine the better type of configuration of Ax-Fem bypass, various hemodynamic conditions of each different configuration were assessed and compared with their clinical experiences.

3. Materials & Methods

The clinical results of two most popular types of Ax-Fem bypass (Inverted-C type and Lazy-S type) implemented to the AIOD at two independent hospitals of Sungkyunkwan University (SKU) and Kyungbook National University (KNU) were assessed through the retrospective review of total 38 cases; 10 cases of SKU during the five year period of 1996. 6 through 2001. 5., and 25 cases of KNU during the ten year period of 1993. 3. through 2002. 2. Clinical review included preoperative clinical status, risk factors and distal run-off scores as a part of hemodynamic assessment. Postoperative clinical outcome was assessed with the primary patency rate through the first and second year. Clinical outcome of Ao-Fem bypass has been used as the gold standard for the comparative study with those of Ax-Fem bypass. Hemodynamic assessment of the five different types of Ax-Fem bypass graft was made based on the values of the flow volume (velocity × area), velocity and pressure in the flow field of each vessel model with different configuration. The velocity and pressure in the flow field of simulation model were calculated based on Navier-Stokes equation using FVM (Finite Volume Method). Blood viscosity variation within the model vessel was expressed using Carreau model. The simulation models of five different configuration was constructed with same condition of inflow and outflow status of steady flow as well as same graft diameter of 8.0 mm and same femoral artery diameter of 9.0 mm for the construction of anastomotic sites. Various hemodynamic informations obtained from each different model including distribution of the pressure, velocity and shear stress in addition to the flow volume distribution were compared with the clinical outcome of Ax-Fem bypass graft.

4. Results

Primary patency rate of total 10 elective Ax-Fem (5 Lazy-S type & 5 Inverted-C type) patients of SKU has been 100% and 80..% for the first year and second year respectively, while total 25 Ax-Fem (all Inverted-C type) patients of KNU have shown 77.7% and 51.8%; 87.6% and 65.6% respectively on elective 16 cases, and 62.5% and 31.3% respectively on emergency 9 cases. There has been no statistically significant differences between Lazy-S type and Inverted-C type on preoperative clinical assessment results as well as the primary patency rate among SKU patients.

All five simulation models of different configuration of the branching graft, including two most popular type (Inverted-C & Lazy-S configuration) have shown significant reduction of the flow volume along the cross-over branching graft to the left lower extremity. Cross-over graft from the right-side located main trunk of the Ax-Fem graft, has shown drastic reduction of flow volume to the wide range of 6.6% to 40.8% of total inflow volume at the anastomotic site to the left femoral artery (Table 1).

However, Model 2 with Lazy-S type configuration (Figure 2) has shown less reduction than Model 3 with Inverted-C type (Figure 3); 29.6% vs 16.9%. Eventhough Model 1 & 4 (Figure 1 & 4) both were designed to

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bring the main inflow to the cross-over left side anastomotic site, only Model 4 with the modification of the branching graft from the main graft on the right side has shown much less reduction (40.8%) of the outflow volume at the left formal anastomotic site. Model 1 was designed to exclude this branching graft with the direct anastomosis of the original right femoral-iliac artery stump (distal) to the side of the main cross-over graft trunk, but it has shown not much improvement of flow shifting to the right and persistant outflow volume reduction to 22.2% of total inflow volume was noticed on left anastomic site.

Among five models, Model 5 was designed to construct cross-over branching graft from the right-side locating main trunk of Ax-Fem bypass graft using right femoro-iliac artery stump (distal) for the anastomosis to the branching graft to the left femoral artery, as the modification of Model 3 to avoid two anastomoses at the same site of right femoral artery. However, it has shown most severe reduction of outflow volume at left anastomotic site to 6.6.% of total inflow volume eventhough it was designed to improve the hemodynamic liability of Inverted-C type by the anastomosis between two grafts.

Model 4, designed to induce the mainstream of inflow to the cross-over left limb by the graft interposition on the right side between the main graft trunk and right femoral artery as a new branching graft, has shown much improvement with the least reduction of outflow volume at the left anastomostic site (40.8%) among five models, however.

Accordingly, the tendency of the major flow volume shift to the right side anastomotic site was quite significant on all five models, including Model 1 (77.8%) which is considered as more advanced model to minimize this risk. Model 3 (83.1%) and Model 5 (93.4%) were worst with increasing risk of critical reduction of the outflow to the cross-over graft to the left side limb. Model 2 with Lazy-S type has theoretically less risk of this critical reduction of flow volume to the left side, comparing to the result of Model 3 with Inverted-C type; shifting of inflow to the right side limb at 70.4% on Model 2 and 83.1% on Model 3.

The degree of shear stress, therefore, has shown the highest level among the Model 1, 3 & 5 along the right anastomotic site due to major shifting of inflow volume to the right side. Model 1, for example, has high degree of shear stress at the right anastomotic site between natural femoral artery to the side of cross-over graft, while it maintains low shear stress on the left side anastomotic site due to this flow distribution. Model 2 and Model 4 both based on same concept of Lazy-S type configuration, however, have shown even distribution of shear stress along the both (left and right) anastomotic sites most probably due to the improved shifting of the outflow volume. Model 5 has shown naturally very low shear stress along the left anastomotic site due to the very low flow volume. Model 3 with Inverted-C type also has shown least recirculation zone on the left anastomotic site most probably due to the drastically reduced flow volume.

5. Discussion

Eventhough Lazy-S type and Inverted-C type configuration of Ax-Fem bypass graft have shown similar clinical results of primary patency rate, their computer simulation models (Model 2 & 3) have shown distinct differences on the distribution of flow volume, shear stress and recirculation zone, etc. Lazy-S type, however has shown better hemodyanmic status than the Inverted-C type, with lesser reduction of outflow volume along the left anastomotic site with even distribution of the shear stress along both anastomoses, comparing to those of the Inverted-C type. But these theoretical advantages even proved by this computer simulation model, has never been able to show clinical advantage with better patency rate and were unable to maintain its initial leading role for the extra-anatomical bypass for AIOD through the last decade. The Inverted-C type slowly replaced the Lazy-S type with better clinical results to become the first choice of configuration for the Ax-Fem bypass graft now. The better clinical results of independent trial of cross-over femoral-femoral (Fem-Fem) bypass graft for the unilateral iliac artery occlusive disease, have given further assurance to the clinical advantage of this hemodynamically more liable Inverted-C type configuration over the Lazy-S type of Ax-Fem bypass. However, the improvement of over-all long term patency rate of various extra-anatomical bypasses is still warranted to match to the gold standard of Ax-Fem bypass through proper correction of the hemodynamic liability due to much reduced outflow volume at one of the two limbs of branched graft, that is left sided cross-over graft anastomotic site by various methods including change of the diameter and/or modification of the anastomotic limb (graft). And also more scrutinizing investigation of these hemodynamic characteristics of each model has to be made in the pulsatile flow status as well.

6. Conclusion

Eventhough clinical outcome of the extra-anatomical bypass for the aortoiliac occlusive disease has been equal, regardless of the type of cross-over femoral graft configuration, there are distinct differences on the hemodynamic characteristics among various types of configuration of axillo-femoral bypass graft. In order to improve the clinical results of this extra-anatomical bypass, further hemodynamic study with computer simulation models in the pulsatile flow status with the modification of the graft condition (e.g. diameter, anastomotic angle) is warranted.