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● *Original Contribution*

MEASUREMENT OF ANASTOMOSIS GEOMETRY IN LOWER EXTREMITY BYPASS GRAFTS WITH 3-D ULTRASOUND IMAGING

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Abstract—The attachment sites of lower extremity bypass grafts are known to exhibit a wide range of geometries. Factors that determine the geometry of a given anastomosis include graft material, graft site, native vessel size, graft size and individual patient anatomy. Therefore, it is difficult to specify a standard anastomosis geometry before surgery and difficult to predict the effect of the geometry on long-term graft patency. We have used 3-D ultrasound imaging to study 46 proximal anastomoses of lower limb bypass grafts. We have developed methods to characterize the 3-D geometry of the anastomosis in terms of component sizes and angles. These detailed geometric measurements describe a range of anastomosis geometries and establish standardized parameters across cases that can be used to relate anastomosis geometry to outcome. (E-mail: leotta@u.washington.edu) © 2005 World Federation for Ultrasound in Medicine & Biology.

Key Words: **3-D, Ultrasound, Bypass graft, Anastomosis, Power Doppler, Vascular imaging.**

INTRODUCTION

Bypass grafting is the standard treatment for extensive lower extremity arterial occlusive disease that causes intermittent claudication, rest pain and tissue loss. The majority of bypass grafts are autogenous greater saphenous vein grafts, but other veins and prosthetic materials may also be used. Vein grafts are classified as either reversed or nonreversed, depending on the direction of implantation. Reversed vein grafts are removed from the patient and then implanted so that the directional valves in the vein allow flow in the arterial direction. In the case of nonreversed vein grafts, the vein direction is unchanged and the valves are cut to allow flow in the arterial direction.

Although the clinical outcomes of infrainguinal bypass grafts are favorable, stenotic lesions develop in up to 40% of grafts, with the majority appearing within the first 2 postoperative years (Mills et al. 1995; Wilson et al. 1995). These lesions are usually related to myointimal hyperplasia and involve both the graft conduit and anastomotic sites. If these stenotic lesions are not recognized and treated appropriately, they can lead to graft thrombosis. Surveillance of bypass grafts with duplex ultrasound (US) can identify these lesions, and routine surveillance programs increase long-term graft patency rates by 10% to 15% (Mills 2001).

The anastomoses between the native artery and the graft are particularly prone to the development of myointimal hyperplasia (Caps et al. 1995; Mills et al. 1993). The factors that contribute to myointimal hyperplasia are not well-established, but they are likely to include hemodynamic effects such as shear stress and mechanical effects such as compliance mismatch (Cole et al. 2002b; Ethier et al. 1998). These factors are, in turn, dependent on the specific anastomosis geometry (Leuprecht et al. 2002). The anastomosis geometry for each case is influenced by anatomical factors encountered by the surgeon, including graft site, available vein and the specific disease distribution. Therefore, the geometry of the anastomosis is often not precisely planned but, rather, is determined by the surgeon at the time of the procedure. The final configuration can exhibit complex shape and flow patterns and there is large variation among patients.

Although standard duplex US can document flow patterns across anastomotic sites, it does not provide information on the 3-D geometry of the vessels. Measurement of vein graft distal anastomosis geometry by magnetic resonance imaging has been previously re-

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ported (Jackson et al. 2003). Three-dimensional US imaging represents another tool with which to evaluate the complex geometry of anastomotic sites. We have previously described measurements of vein graft geometry at revision sites by 3-D US (Leotta et al. 2003). This report presents methods to define 3-D anastomosis geometry and measurements compiled from 3-D US scans of 46 proximal anastomoses of bypass grafts in the lower limb. The results provide a quantitative description of both the typical configuration of the proximal anastomosis and the range of configurations observed at our institution.

METHODS

Imaging system

Three-dimensional US imaging is performed using a custom system developed in our laboratory (Leotta et al. 2001). A magnetic tracking system (Flock of Birds, Ascension Technology, Burlington, VT, USA) is used to register 2-D US images in a 3-D coordinate system. This system was calibrated by the procedures described in Leotta et al. (1997); the precision for locating a point target was measured as 0.7 mm. The US imager (Sonos 5500 and HDI 5000, Philips Medical Systems, Bothell, WA, USA) and magnetic tracking system are interfaced with a personal computer equipped with a frame grabber board and custom software for simultaneously acquiring the US images and the associated location data. Data acquisition is initiated by a hand switch and gated to an ECG signal.

3-D scanning

Patients who have had a graft placed in the lower limb to bypass areas of arterial obstruction were asked to participate in an US follow-up study. The imaging protocol was approved by the institutional review board and all subjects gave informed consent. Examinations were performed with the patient on a wooden bed to minimize distortions of the tracking system's magnetic fields caused by ferromagnetic material in the vicinity. The patient was positioned so that the graft was lying within the range of the transmitter, which was mounted underneath the bed. The patient was instructed to lie quietly and not to move the leg during the examination.

Cross-sectional images were obtained through the proximal graft anastomosis, including the native inflow artery, the proximal graft and patent native vessels distal to the anastomosis. Imaging was performed in the power Doppler mode, with the grey-scale background image included. The 2-D images were gathered at intervals of 1 to 2 mm along the area of interest. For each image, the operator held the scan head stationary and enabled the capture program on the personal computer through a hand switch signal. A single image frame and the corresponding location data were then saved at the next detected ECG trigger signal. The ECG trigger was set to ensure that the data were gathered at the maximum velocity, which is slightly after systole. An audible signal indicated that the data had been saved, after which the operator positioned the scan head at the next location. A set of images of an anastomosis, typically between 25 and 50 images covering 4 to 8 cm, was acquired in 3 to 5 min.

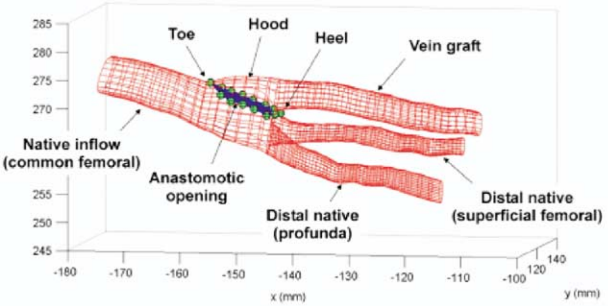

Fig. 1. Components of a graft proximal anastomosis that are used for analysis of 3-D geometry. The anastomotic opening is the 3-D polygon defined by the spheres superimposed on the mesh reconstruction. Location and orientation of the anastomosis within the 3-D coordinate system of the magnetic transmitter are determined by the position of the patient's leg during the scan.

Reconstruction

Custom software using the MATLAB programming environment (The MathWorks, Natick, MA, USA) has been developed in our laboratory for the reconstruction of 3-D surfaces from cross-sectional images (Leotta et al. 2001, 2003). Automatic color segmentation defines the boundary of the lumen on each of the 2-D cross-sectional power Doppler views of the vessel. The automatic segmentation is reviewed and manually edited, if necessary. The automated segmentation follows the main flow channel, including the native vessel and the bypass graft. The contour points are transformed to locations in the 3-D coordinate system of the magnetic transmitter by use of the position and orientation information associated with each image plane. Contour points are connected by computer software to neighboring outlines to generate a surface model of the vessel. Visualization functions in MATLAB allow the user to freely rotate the surface reconstruction to view the full 3-D geometry of the vessel.

The surface reconstruction is divided into a set of structures that, together, are used to derive standard 3-D geometry parameters for comparison across all anastomoses (Fig. 1). The structures are 1. the native inflow artery, 2. the bypass graft, 3. the anastomotic segment,