

Lower extremity peripheral vein bypass graft wall thickness changes demonstrated at 1 and 6 months after surgery with ultra-high spatial resolution black blood inner volume three-dimensional fast spin echo magnetic resonance imaging

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Abstract Objective To demonstrate lower extremity peripheral vein bypass graft wall thickness changes over time in a patient using very high spatial resolution cardiac gated, black blood inner volume three-dimensional (3D) fast spin echo (FSE) magnetic resonance imaging (MRI). **Case report** A 52-year-old diabetic man with a history of hyperlipidemia underwent uncomplicated bypass grafting for an asymptomatic 5.2 cm popliteal artery aneurysm using reversed great saphenous vein. A segment of the bypass graft was studied at 1 and 6 months after surgery with cardiac gated inner volume 3D-FSE imaging with non-interpolated 0.195 mm³ voxel volumes (0.3125 × 0.3125 × 2 mm). T1- and T2-weighted images were acquired in 10 min per contrast weighting. Graft imaging at one month after implantation illustrates expansion of the outer wall of the graft that partially resolves 5 months later. **Conclusion** In this patient, expansion of the lower

extremity peripheral bypass graft wall can be characterized in clinical scan times with a 3D-FSE MRI protocol using highly selective inner volume excitation followed by non-selective refocusing pulses. The resulting 3D images can potentially be used to study the biology of the vessel wall.

Keywords Lower extremity bypass graft
Magnetic resonance imaging /
vascular remodeling
Vessel wall imaging

Case report

Clinical

The patient is a 52-year-old diabetic man who presented with an asymptomatic 5.2 cm popliteal artery aneurysm. The aneurysm was lined with mural thrombus, but there was no evidence of distal embolism. He is an otherwise healthy nonsmoker, and he exercises regularly. He has no history of hypertension, dyslipidemia, connective tissue disease, or vasculitis. Other than the popliteal aneurysm, he has no ultrasound evidence of peripheral artery disease. He underwent a superficial femoral artery to below knee popliteal artery bypass using ipsilateral reversed greater saphenous vein ligation and exclusion of the popliteal artery aneurysm.

At 1 and 6 month follow-up, the patient reports no complication. Clinical duplex ultrasound surveillance

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scans of his bypass graft demonstrate stable peak systolic velocities with no hemodynamically significant stenosis.

Imaging

As part of an IRB approved research protocol and after written informed consent, the patient underwent T1- and T2-weighted MRI at his 1 and 6 month follow-up visit (Fig. 1). Imaging was performed using a 1.5 T Excite HD MR scanner (GE Medical Systems, Milwaukee, WI) using the body coil for radiofrequency (RF) transmission and a 5 in. circular surface coil for reception.

Meticulous image registration ensured that the identical segment of the bypass graft was studied at 1 and 6 months post-implantation. At surgery, the graft segment to be imaged was prospectively identified by marking its distance from the proximal anastomosis and from the tibial tuberosity. The proximal aspect of the segment was also noted at surgery by the placement of metallic clips on nearby side branches. Immediately before both MRI scans, the location of the anastomosis and the position of the clips were identified by sonography, and the skin overlying the proximal point of the imaged segment was marked by pen (for proper placement of the circular surface coil), plus a vitamin E tablet that is readily identified by MRI. The proximal end of the imaged segment was then confirmed with bright blood time-of-flight images that allowed for careful measurement to the proximal anastomosis of the graft. Prior to the inner volume 3D-FSE sequences, these measurements were confirmed with the data recorded at surgery.

The 3D-FSE sequence (Fig. 2) incorporates an inner volume spin selection method composed of a pair of RF pulses to reduce the imaged field-of-view (FOV) to a 3.09 × 3.09 × 3.6 cm volume that encompassed the graft [2, 3]. The volumetric encoding was performed with a 96 × 96 × 18 (frequency × phase × slice) matrix with slice phase encoding aligned along the course of the graft. Non-interpolated spatial resolution was thus 0.3125 × 0.3125 × 2 mm (0.195 mm³ voxels).

Discussion

The 5-year primary patency rate for lower extremity peripheral vein bypass grafts ranges from 60 to 85%

[4]. Because lower extremity peripheral vein bypass graft failure has significant morbidity and mortality, graft lumens are periodically screened with ultrasound. Sonography demonstrates the late changes of lumen stenosis but does not have the inherent soft tissue contrast needed to characterize early vessel wall changes.

Because the pathophysiology of lower extremity peripheral vein bypass graft failure is poorly understood, those grafts that fail are typically categorized into temporal phases as opposed to a categorization based on pathophysiology (i.e., wall thickening and its effect on the lumen). Early graft occlusion (within post-operative day 30) occurs in 5–10% of cases and is generally ascribed to technical complications but also includes problems intrinsic to the conduit (e.g., pre-existing vein pathology) and extrinsic causes such as a hypercoagulable state. Mid-term lower extremity peripheral vein bypass graft failure is defined as 1–24 months. Failure in these patients is poorly understood; it has been postulated that excessive wall thickening, manifest primarily as neointimal hyperplasia in contrast to medial hypertrophy, is a critical determinant [5]. Late (>2 years) failure is hypothesized to be caused by atherosclerotic degeneration.

After surgery, thickening of the arterialized vein has been described and attributed to increased wall tension [6]. During this process, a hyperplastic neointima normalizes tangential wall stress. [One hypothesis is that excessive wall thickening, manifested primarily as intimal hyperplasia in contrast to medial hypertrophy, is a critical step in those grafts that succumb at mid-term [5, 8]. Lower extremity peripheral vein bypass graft sonography supports that successful grafts will undergo structural changes but maintain luminal caliber [9, 10]. However, the 20–30% of patients who fail over the first 6 months undergo aggressive lumen narrowing. The vessel wall tissue properties in these patients are essentially unknown.

Because of the inherent soft tissue contrast, MRI is desirable as a research tool to describe and possibly separate small changes representing the normal physiology versus changes that will ultimately lead to disease requiring intervention [1]. However, to detect early change in thin vein grafts, current clinically available pulse sequences have limitations primarily related to the tradeoff between spatial

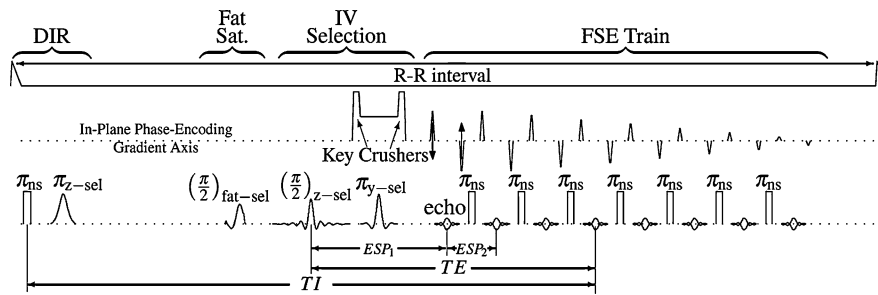


Fig. 2 Pulse sequence diagram for inner volume three-dimensional fast spin echo technique. The readout and section-encoding axes (not shown) are identical to those of a standard 3D-FSE sequence, with the exception of slab-selective gradients which are not applied during any of the refocusing excitations in the FSE train. The double inversion recovery blood nulling module is composed of a non-selective 180 (π_{ns}) excitation followed by a slab-selective 180 (π_{z-sel}) excitation. This is followed (for T2 but not for T1 contrast weighting) by a frequency-selective fat saturation pulse ($\pi/2_{fat-sel}$) and associated dephasing gradients. Subsequently, inner volume selection is performed using a 6.2 ms, 19.2 kHz-ms 90 Shinnar-DLE Roux (SLR) slab-selective excitation ($\pi/2_{z-sel}$) followed by a 3.2 ms, 5.12 kHz-ms 180 slab-selective SLR refocusing pulse (π_{y-sel}) applied so as to

refocus a slab orthogonal to that excited by the pulse. Although the long duration of these pulses delays the first echo formation, which occurs at approximately 12–14 ms, the problem of the 90 large time-bandwidth excitation achieves a 2.3 mm transition thus requiring only one additional slice be oversampled at each end of the inner volume. The FSE train is subsequently formed by tightly-spaced 0.5 ms-long non-selective refocusing pulses (π_{ns}). In order to avoid refocusing of transverse magnetization generated by the slab-selective excitation by these refocusing pulses, the slab-selective refocusing pulse is sandwiched by a pair of “key” crushers applied along the in-plane phase encoding axis. The dephasing induced by these crushers remains unbalanced for the entirety of the echo train since the phase encoding gradients in the FSE sequence are rewound following each echo formation

this technique yields higher spatial resolution than the 6 month T1- (Fig.1e) and T2- (Fig.1f) weighted previous methods for the same scan time. There are also specific advantages of 3D in vivo techniques for vessel wall imaging when compared with two-dimensional (2D) sequences. While 3D methods in general lead to longer imaging times, the effective averaging due to section encoding results in increased signal to noise ratio needed to achieve sufficiently high resolutions to avoid partial volume effects. Furthermore, black blood double inversion recovery modules for vessel wall imaging make single slice, or few slice, 2D techniques relatively inefficient from a volume coverage per unit time perspective.

Extending the discussion to vessel wall imaging in general, imaging vessels with even slight curvature introduces partial volume effects that negatively impact vessel wall characterization. Moreover, lesions that require meticulous characterization tend to develop at branch points such as at an anastomosis

Because in this patient the graft lumen was normal at both 1 and 6 month scans, the patient could not have intravascular ultrasound or histology confirmation of imaging findings. However, it is interesting to speculate how very high spatial resolution in vivo MR images correlate with graft wall histology. On

the 1 month images) to the very thin intima plus the media. Under this assignment, the wall expansion at one month is secondary to an asymmetrically thickened adventitia. To date there is little known regarding this biological process, but it is likely to include wound healing (including inflammatory deposits) and the development of microvessels.

Although less likely, it is possible that the graft wall thickening represents positive remodeling. While this would support the hypothesis that vessel wall changes occur early [1, 18, 19], remodeling is conjectured to be a flow-induced endothelial-dependent response to the acute increase in shear stress [18] that remains over time. In this patient the wall thickness regresses at 6 months after surgery. Nevertheless, there is very little high spatial resolution data studying early changes in lower extremity vein grafts. The vast majority of in vivo human graft remodeling data are from intravascular ultrasound in the heart.

While the surface coil used in this study has limited penetration, the superficial position of lower

extremity bypass grafts enables the reception of a sufficiently large MR signal to achieve the spatial resolution necessary to visualize changes in wall thickness at 1 month and its normalization by 6 months after surgery. In addition, the T1-weighted and T2-weighted images have different properties, with the vessel wall appearing thicker in the T1-weighted images. Validation would require examination in several patients, but it is interesting to hypothesize that those differences between T1 and T2 areas correspond to components of the vessel wall. As we continue to modify and improve the inner volume 3D-FSE pulse sequence, we will incorporate a dual effective echo technique into the FSE readout. This will allow the generation of both proton density as well as the T2-weighted images without misregistration, but at the expense of additional scan time (approximately 10 min using the current strategy). Future work will incorporate phased array coils and implementation on 3 T MR systems, enhancing the signal-to-noise ratio, which can in turn be traded for increased spatial resolution and/or decreased scan times with parallel imaging techniques [20].

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