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Peripheral Magnetic Resonance Angiography with a Multi-Compartment Curved Leg Wrap for Thigh Compression

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ABSTRACT

A curved urethane rf-welded leg wrap with multi-compartment inflation was developed for optimal thigh compression to suppress venous enhancement during peripheral magnetic resonance angiography (MRA). In 49 patients with suspected peripheral vascular disease, bilateral thigh leg wraps were inflated to 60 mm Hg just prior to mask imaging of 3D bolus chase peripheral MRA at 1.5 T using 45 mL gadolinium contrast agent. The time from contrast arrival in the abdominal aorta to venous enhancement in the calf was measured by repeating the calf station at ∼30 second intervals until venous contamination was observed. The mean time to venous enhancement with thigh compression was 108 ± 35 s, ranging from 40 to 181 s. In 64 out of 98 legs (65%), veins did not enhance even after repeating the calf station 3 times. In 10 legs (10%), venous enhancement was identified on the first phase of the calf station including 2 legs with cellulitis. However, the enhancing veins tended to be superficial and did not substantially interfere with visualization of calf arteries. This preliminary experience with a curved multi-compartment leg wrap for thigh compression shows high quality MRA with a long window of arterial enhancement and a minimum of venous contamination.

INTRODUCTION

Multi-station bolus chase peripheral MRA has revolutionized diagnosis of peripheral vascular disease because it allows rapid imaging from the aorta to the pedal arteries in a few minutes with a single injection of gadolinium contrast agent. The patient is advanced through the scanner as the gadolinium flows down the peripheral arteries so the same contrast bolus can be imaged three times as it passes through the abdomen/pelvis, thigh and calf stations. In this way the bolus is shared among imaging stations covering the peripheral vasculature, offering rapid, safe, high SNR and accurate evaluation of arterial occlusive disease with no risks from ionizing radiation, arterial catheterization or iodinated contrast (1–11).

However, in many patients, the gadolinium contrast bolus travels so quickly down the legs that the MR scanner is not able to optimally image and move the table fast enough to keep up. In these patients with fast flow, the bolus is not optimally shared and venous enhancement can occur in the distal stations interfering with visualization of the calf arteries and limiting diagnostic utility (9, 12). Venous enhancement, known as venous contamination, is observed in up to 50% of patients, especially those with diabetes, cellulitis or foot ulcers due to rapid arterio-venous shunting. In order to minimize venous enhancement in the distal stations, one solution is to image faster at the expense of spatial resolution and anatomic coverage. However, calf arteries are small in caliber and require high spatial resolution MR angiograms. In addition, some calf arteries with occlusive disease may fill slowly especially if filling occurs via retrograde flow from collaterals. Therefore, it is crucial to keep the arterial phase of the distal station sufficiently long for high spatial resolution and to allow more time to fill all arteries with the contrast agent.

An approach to eliminating venous contamination has been initially described in 1999 by Meaney et al using tourniquets to slow down arterial blood flow and suppress venous enhancement in the calf (13). Tourniquets are commonly utilized in extremities

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to reduce blood flow, which can be applied lightly to occlude only venous flow or more tightly to reduce or arrest arterial flow. In peripheral MRA, a tight tourniquet is not favorable. It creates artificial arterial narrowing simulating a false stenosis or occlusion and interferes with assessment of peripheral arteries. However, when applied lightly, only venous return is slowed down without interfering with arterial caliber.

In clinical practice, it is more reliable and more effective if the compression is applied with blood pressure cuffs inflated to a precise pressure (14). Compared to tourniquets, a standard thigh blood pressure cuff, which is approximately 6 inches wide, can be inflated to a sub-systolic pressure over longer length of the leg to give more uniform and effective venous compression (14). Since commercially available thigh blood pressure cuffs are not designed for sustained sub-systolic compression in MRA, they tend to leak and slide down the thigh becoming loose. The asymmetrical inflation of the bladders pushes on the leg and changes its position causing misregistration between different phases.

A curved leg wrap designed to fit the conical shape of the thigh with inflation around the entire leg circumference overcomes these limitations. In this study, this dedicated curved cuff wrap was tested in 49 patients by measuring the time to venous contamination in the calf station of 3D bolus chase peripheral MRA.

MATERIALS AND METHODS

Dedicated Thigh Cuffs

The curved leg wrap is illustrated in Fig. 1. A 4-foot radius of curvature is optimized for snug fitting to the average size thigh, which is larger cranially and smaller caudally. Fifty-nine spot welds restrict the expansion in any one location ensuring a uniform inflation/compression that minimizes impact on leg position. Inflation to 60 mm Hg can be with a MRI compatible hand pump with a pressure gauge to monitor inflation pressure or with a MRI compatible regulator connected to a pressurized air or oxygen source in the MRI scanner room (Smart Tourniquet, Topspins, Ann Arbor, Michigan, USA) (15).

Patients

From April 1, 2005 to January 3, 2006, 49 consecutive patients were referred for contrast enhanced peripheral MRA with indications of claudication (n = 39), cellulitis (n = 2), ulceration (n = 3), post-operative surveillance (n = 5). There were 28 males and 21 females, ranging in age from 29 to 95 (mean age = 67 years). A total of 98 legs were analyzed. This study with curved cuffs was approved by local institutional review board.

MR Imaging

All imaging was performed on a single 1.5 T MR imaging system (GE Signa-EXCITE, General Electric Medical System, Milwaukee, Wisconsin, USA). For the bolus chase MRA, 45 mL of gadolinium contrast (Magnevist, Berlex Lab, Wayne, New Jersey, USA) was injected manually at ~2 mL/sec with a tubing system (SmartSet, TopSpins, Ann Arbor, Michigan, USA) via a 20 or 22 gauge angiocatheter following by 30 mL saline flush. A multiphase 3D spoiled gradient-echo sequence with dynamic k-space sampling was employed for the bolus chase MRA acquisition using a 48-cm phased array coil (ICG Med Advances, Milwaukee, Wisconsin, USA) for signal reception at the calf station and body coil for the abdomen-pelvis and thigh stations. The scanning parameters were: TR/TE/flip angle = 4.4 ~ 4.6/1.1/30°; field-of-view (FOV) = 48 cm; slice thickness = 2–4 mm with zero filling interpolation to 1–2 mm, NEX = 1, bandwidth = 62.5 kHz. The matrix was 512 × 160 for the first station, 512 × 160 for the thigh and 512 × 320 for the calf.

Thigh Compression

Curved thigh cuffs were applied as proximal as possible on the thigh and were inflated to 60 mm Hg just before the pre-contrast mask imaging (Fig. 2). Due to the slow air leakage caused by long blood pressure cuff tubing and extra connections, cuff pressure was monitored during the interval between mask and arterial phase imaging and puffs of air were applied when the pressure drifted down to maintain an inflation pressure of

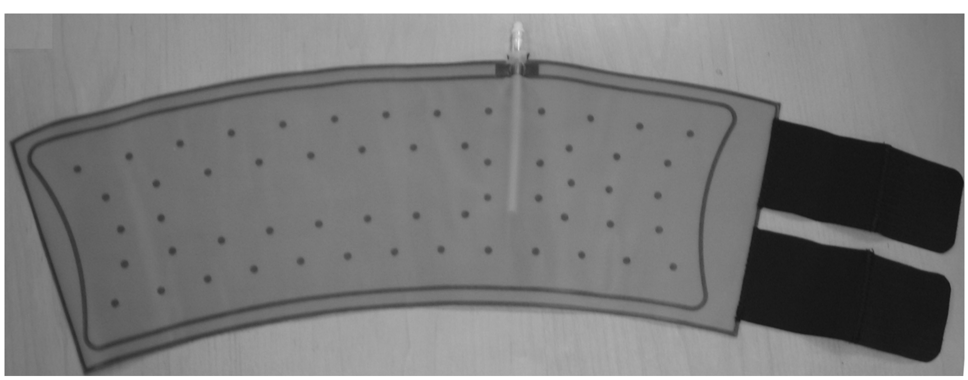

Figure 1. Curved leg wrap with 59 spot welds. The curved shape better fits the thigh to prevent sliding down the leg. The spot welds ensure uniform inflation.

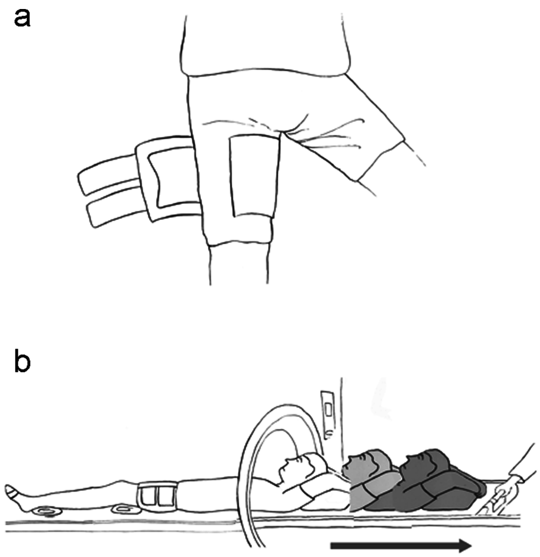

Figure 2. Curved thigh cuffs are applied on the thigh as proximal as possible (a) and are inflated to subsystolic pressure (60 mm Hg) prior to mask imaging (b).

50–60 mm Hg. For the last 8 patients, a MRI compatible regulator was developed, which allowed continuous maintenance of the 60 mm Hg pressure from a pressurized oxygen source.

Bolus Timing

The first station was timed with fluoroscopic triggering and sequential ordering of k-space during 18–20 seconds of breathholding. Using fluoroscopic monitoring of the abdominal aorta in a sagittal oblique plane, the operator activated the trigger as soon as contrast appeared. Then there was a 4-second pause to instruct breathholding before the 3D MRA scan was initiated. The time between initiating injection and initiating the first station scan was recorded by the investigator. The second and third stations utilized elliptical centric ordering of k-space, and the acquisition time was 12–15 seconds and 29–40 seconds, respectively, depending upon the number of slices. The calf station scanning was repeated up to 4 times until venous enhancement was observed by the operator.

Image Analysis

The MRA data were analyzed on a computer workstation by two radiologists (K.M. & H.L.Z.), blinded to all clinical information. These two radiologists reviewed the 3D MRA source images of the calf station to determine when contrast appeared in the veins utilizing the criteria of visualizing contrast enhancement in either deep veins or superficial veins or both. Each leg was analyzed independently. The incidence of misregistion artifacts was also evaluated by the investigators.

The time between initiation of thigh station and venous enhancement (T_V) was calculated using the scanner clock, which was verified to have accurate interval timing except for the first station. Because the time for the first station (abdomen-pelvis) included the time to start fluoroscopic triggering, the time interval between the first and second stations based on the scanner clock was not accurate. To calculate the time between when contrast arrived in the aorta and when the thigh station began, we added 7 seconds to the first station scan duration. This 7 seconds included 4 seconds for breathhold instruction and 3 seconds for table movement. In some patients, venous enhancement was not observed even after 4 repetitions of the calf station. Under this condition we conservatively assumed that venous enhancement would have occurred on the next acquisition for the purpose of calculating venous arrival time. Contrast travel time was shown as mean ± SD.

RESULTS

None of the subjects had difficulties with cuffs sliding down the thigh or leaking excessively as has been observed with standard thigh blood pressure cuffs. There was also minimal misregistion artifact, which could occur when inflation of an assymmetric bladder shifts the leg into an uncomfortatble, precarious position.

In 49 patients with subsystolic thigh compression using multi-compartment, curved blood pressure cuffs inflated to 60 mm Hg; the average time between contrast arrival in the abdominal aorta (detected by fluoro-triggering) and calf vein enhancement was 108 ± 35 s (ranging from 40 to 181 seconds) (Figs. 3 and 4). In 64 out of 98 legs (65%), venous enhancement only occurred after repeating the calf station 3 times (~2 minutes).

In 10 legs (10%), venous contimination was identified on the first phase. In 6 of these legs, enhancing veins tended to be superficial and did not substantially interfere with visualization of calf arteries. In the remaining 4 legs, popliteal veins enhanced on the first phase, of which 3 had enhancing soft tissue enhancement in the calf with known foot ulcer (n = 1) or cellulitis (n = 2). The fourth leg showed fast arterio-venous shunting on time-resolved MRA (veins enhanced at 34 seconds after injection immediately following arterial enhancement).

DISCUSSION

Benefits of thigh compression

Thigh compression or Venco (venous compression) is rapidly becoming an important element of bolus chase peripheral and whole body 3D gadolinium enhanced MRA to consistently obtain arteriograms free of venous contamination. In order to reduce venous contamination in the calf and eliminate the problem of not fitting on the thigh, infragenual compression with a set of standard blood pressure cuffs has been introduced by some authors (16). Other authors advocate cuffs on the thigh to produce better suppression of the venous enhancement over a longer length of the extremities (14, 17–19). However, standard blood pressure cuff designs are not appropriate for uniform, sustained and precise thigh compression. To better compress the venous enhancement when performing bolus chase peripheral MRA, there is a need for a new design of thigh compression device.

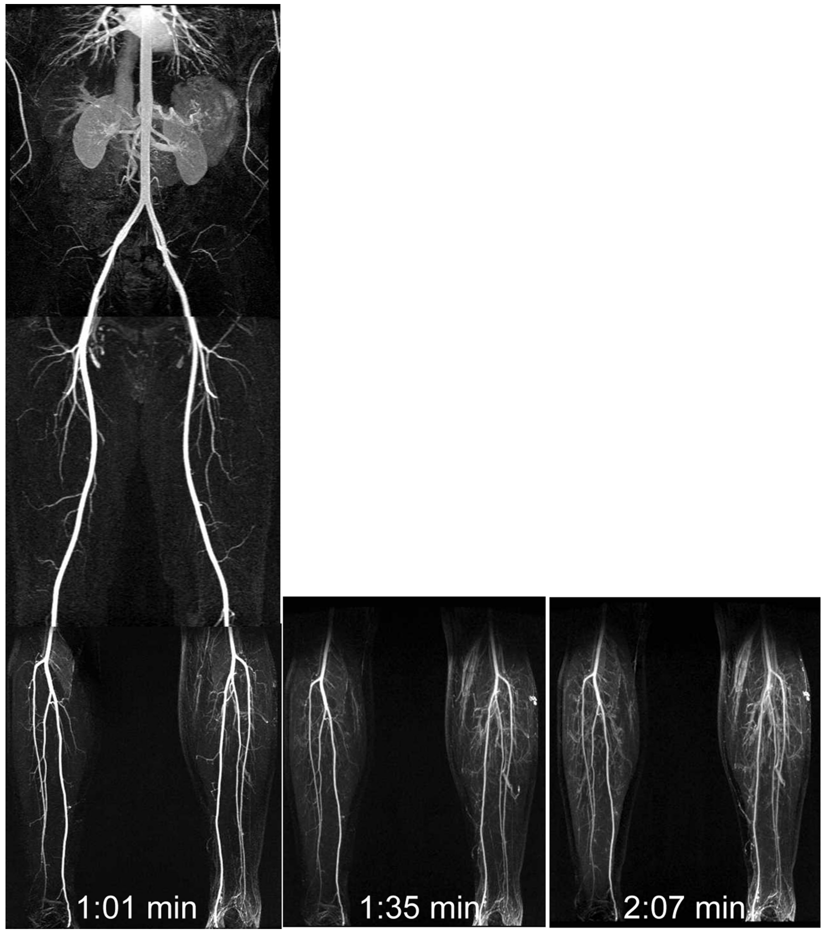

Figure 3. Fifty-two year old male with claudication. Venous enhancement was identified on the second phase of calf station. The time from contrast arrival in the aorta to the beginning of each calf station (with elliptical centric ordering of k-space) are indicated at the bottom of each image.

Advantages of multi-compartment curved leg wrap

These data in 49 patients demonstrate the benefits of utilizing a multi-compartment, curved urethane leg wrap shaped to the thigh for more homogenous compression and a better fit that is less likely to become loose by sliding down the thigh. These data show this design delays venous enhancement to a mean of 108 seconds following gadolinium arrival in the abdominal aorta. This is a 1.6-fold prolongation compared to 67 seconds for venous enhancement in 87 patients with similar indications from the same institution (20). This extra time can be used to increase time for higher resolution scanning with increased signal-to-noise ratio (SNR). Alternatively, more stations can be acquired to extend MRA to other body regions including the chest and head, making whole body MRA more robust (17, 19).

Inflating with a pressurized oxygen source

The problem of leaking initially required periodical puffs of air from the hand inflator. Later this problem was completely eliminated by using an MR compatible regulator that steps the 50 pounds per square inch (psi) oxygen typically available throughout hospitals down to 60 mm Hg ($\sim$1.1 psi) for sustained cuff inflation. This work-in-progress can also eliminate the cumbersome task of hand pumping air into two large thigh cuffs which are substantially larger than the cuffs used for measuring blood pressure on the arms. By operating directly off pressurized air/oxygen, no electrical pumping mechanism is required which further enhances MR compatibility.

Study Limitations

Even with precisely-controlled thigh compression, venous contamination can not be completely eliminated. In this study, 10% of legs (n = 10) had venous contamination of different significance. In 4% (n = 4, 2 legs with cellulites, one with ulceration and one with rapid arterio-venous shunting), the venous contamination did interfere with diagnostic quality. Accordingly, in those patients with rapid AV transit related to

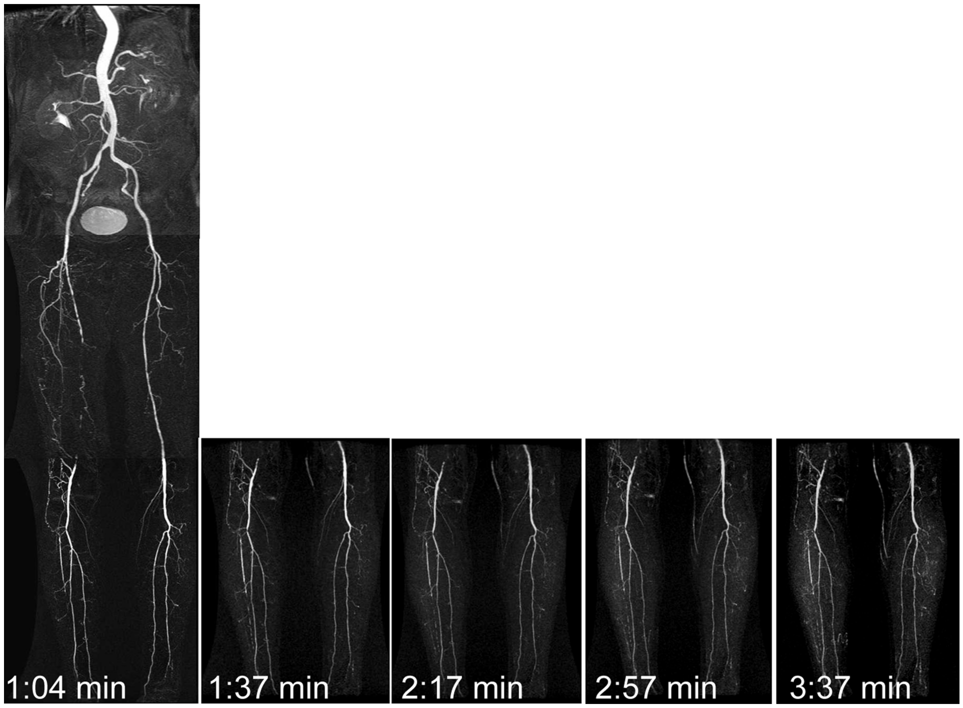

Figure 4. Seventy-five year old male with rest pain. Calf veins did not enhance until the fifth phase of calf station. The time from contrast arrival in the aorta to venous enhancement in the calf is >3 minutes.

cellulites, ulceration or arterio-venous shunting, the ultimate solution should be a time-resolved MRA of the calf prior to performing bolus chase MRA.

In this study, the temporal resoution of the third station was about 30 seconds based on the actual duration of routine 3D MRA sequences in order to get enough spatial resolution and SNR. A higher temporal resolution would be helpful to more precisely determine the potential of this curved leg wrap for delaying venous enhancement. Furthermore, the best comparison should be made with and without compression in the same patients. Manual contrast injection also introduces a potential bias if the injection rate is not exactly identical for different patients. This potential bias cannot be entirely eliminated by use of power injectors because all power injectors are activated manually and the power injectors may also have inconsistent injection rate depending on the iv resistance.

A common drawback of thigh compression is that it cannot be utilized in patients with severe rest pain. Extra care is needed in patients with superficial thigh grafts to avoid excessively compressing a graft and precipitating thrombosis. This problem cannot be easily resolved by specific design of the leg wrap. Another limitation to consider is that applying thigh compression alters the hemodynamics such that time-resolved information is no longer accurate. Accordingly, thigh compression is not recommended when performing time-resolved peripheral MRA.

CONCLUSIONS

Subsystolic thigh compression reduces venous contamination in the calf allowing more time for arterial filling and to acquire higher resolution, higher SNR images. With this technique, bolus timing becomes less critical in peripheral MRA. High quality bolus chase exams can be obtained by technologists with a lower skill level and less training than what was previously required. Our experience in 49 bolus chase MRA studies suggests that this new design cuff provides robust suppression of venous contamination as long as there is no cellulitis, ulceration or rapid arterio-venous shunting. The curved cuffs are intuitive to use and minimize air leaking, cuff loosening and leg position shifting problems of standard thigh cuffs.

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