Pitfalls in Cuff-induced Ischemia Studies Using BOLD MRI

David K.W. Yeung[1], James F Griffith[2], Heather T Ma[2,3], and Alvin F.W. Li[4]

[1]*Imaging and Interventional Radiology, Prince of Wales Hospital, Shatin, HKSAR, Hong Kong,* [2]*Imaging and Interventional Radiology, The Chinese University of Hong Kong, Shatin, Hong Kong,* [3]*Department of Electronic and Information Engineering, Harbin Institute of Technology, China, People's Republic of,* [4]*Imaging and Interventional Radiology, The Chinese University of Hong Kong, Shatin*

Background: Functional MRI technique relies on blood oxygenation level-dependent (BOLD) effect, which is sensitive to changes in local tissue deoxyhemoglobin concentration. This technique is widely used in human brain activation mapping and also in human skeletal muscle perfusion studies. Muscle perfusion may be examined after cuff-induced ischemia by inflating an air-cuff above the knee. However, little is known whether the presence of an inflated cuff holding a pocket of high-pressure air could influence the local magnetic field susceptibility causing aberrant T2* signal intensity changes.

Introduction: BOLD imaging to study muscle reactive hyperemia after release of a pressure cuff may be useful for the examination of patients with peripheral arterial disease and for monitoring of therapies aimed at improving perfusion (1,2). Following blood-flow disruption, both deoxyghemoglobin and deoxygmyoglobin start to accumulate leading to a drop in T2* signal intensity because of their paramagnetic properties. However, it is unclear whether such a sensitive sequence capable of detecting very small changes in local magnetic field strength might also be modulated by high-pressure air used to inflate the cuff. Our aim was to verify the effect of air-cuff inflation on T2* signal intensity using phantoms and human subjects.

Theory: Volume susceptibility (χ) of a gas is dependent on both pressure and temperature and is given by the equation: $\chi = \chi_o(PT_o^2/P_oT^2)$ where χ_o is the volume magnetic susceptibility at 1 atm and 0°C (3,4). The volume susceptibility of air is primarily determined by oxygen gas (21%) which is a paramagnetic molecule. Assuming temperature is kept constant, an increase in air-cuff pressure therefore leads to a proportional increase in χ. Thus, air-cuff pressure may have a direct effect on air susceptibility, causing a local magnetic field shift in nearby objects which in turn may lead to signal intensity changes on T2*-weighted images.

Materials and Methods: *Phantom Experiments.* Two plastic bottles (diameter 12 cm, length 27 cm) filled with mineral oil were taped together end-to-end to form one long phantom to simulate the human lower limb. This study was performed on a 3T whole-body clinical scanner. The phantom was securely placed inside a SENSE knee coil positioned at the iso-centre of the magnet. A thigh air-cuff (38-50 cm) was wrapped around one of the bottles and fixed with a Velcro strap to prevent loosening. Air-cuff inflation was achieved using a sphygmomanometer (Spacelabs Healthcare, Redmond, WA) and after the air-cuff was inflated to the desired pressure, a T2* sequence (TR/TE 372/40 ms; slice thickness 5 mm; NEX 1; FOV 250 mm; dynamic measurements 500; scan time 180 s) was applied to acquire one axial slice located 15 cm away from proximal side of the air-cuff. Four air pressure levels ranged from 120-170 mmHg were tested. The first 60 s of the dynamic measurements were obtained after the air-cuff was inflated and a further 120 s measurements were acquired after air-pressure was released.

Human Studies. Fourteen healthy volunteers (7M, 7F; mean age, 42 years) were examined using a similar T2* sequence (FOV 330; dynamic measurements 2400; scan time 900 s). A thigh air-cuff was placed just above the left knee and the imaging plane was centred at the largest section of the calf. A cardiac coil was employed to acquire dynamic images from both legs. The timeline for air-cuff inflation: 0-60s ambient pressure; 61-360 s air-cuff inflated to a pressure 50 mmHg above the subject's systolic pressure; 361-900 s ambient pressure. Muscle T2* signal changes due to blood flow interruption in the left calf was examined and aberrant T2* signal changes caused by air-cuff inflation in the right calf at rest was also investigated.

Results: *Phantom.* Most regions of the phantom did not show observable T2* signal changes as air-cuff pressure was varied. However, in some peripheral areas of the phantom, a noticeable steep drop in signal intensity was observed (Fig. 1). The magnitude of T2* signal drop appeared to depend on air-cuff pressure. The maximum signal change for the highest applied pressure (170 mmHg) with the cuff placed at a distance of 15 cm was about 3.7%. For the lowest air pressure (120 mmHg), the signal change was about 2%. All phantom data showed the same characteristic abrupt signal drop when air-pressure was released and the signal settled at the same intensity level when air-cuff pressure was equal to the ambient pressure.

Human Studies. With air-cuff applied in the left thigh, the left calf muscles of all subjects showed progressive T2* signal drop after air-cuff inflation due to paramagnetic deoxymyoglobin accumulation. However in all subjects, there were muscle areas where a sudden drop in T2* signal could be observed at the instant of air-cuff inflation. This pattern of steep signal drop was also observable in the right calf where blood oxygenation was normal. Figure 2 shows an example of T2* signal evolution in the tibialis anterior observed in both calves of one subject. Aberrant air-cuff induced signal change was characterized by an abrupt signal drop followed by a period of steady signal while air pressure was held constant (Figure 2, red trace (right leg)). In contrast, physiological changes showed a more progressive signal evolution as deoxymyoglobin gradually increased after blood flow was interrupted (Figure 2, blue trace (left leg)).

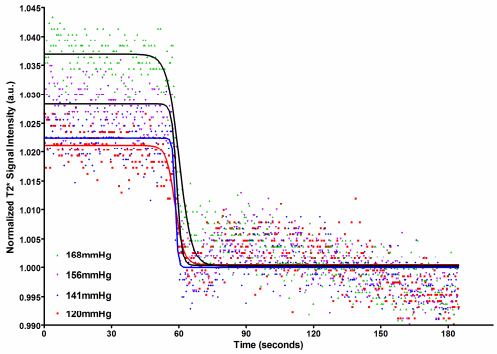

Fig. 1

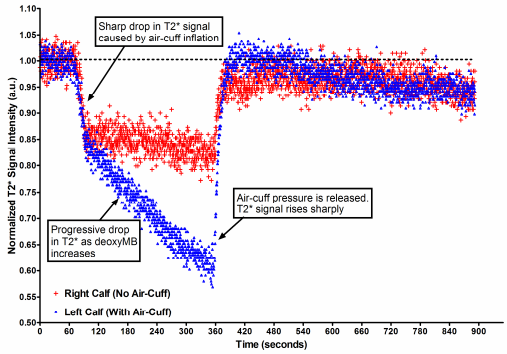

Fig. 2

Conclusion: Our phantom experiments confirmed that air used to inflate air-cuffs in muscle perfusion studies may induce aberrant T2* signal changes. The magnitude of this effect was dependent on the level of applied pressure. Air-cuff induced effects were characterized by an abrupt signal drop, followed by a period of steady signal when air-cuff pressure was held constant. In human studies, we found noticeable T2* signal changes in the opposite calf muscle even when blood circulation was normal. Our results confirmed the hypothesis that oxygen in air at high pressure may exhibit non-negligible magnetic susceptibility properties that may lead to local magnetic field disturbances and that T2* imaging sequence is sensitive to the effect of an inflated air-cuff. Although high pressure air in air-cuff may affect T2* muscle perfusion data, its contribution might be accounted for in perfusion time-series datasets as it is clearly presented in the form of a sharp T2* signal drop (Figs. 1,2) coinciding with the moment of air-cuff inflation or deflation. With this knowledge, muscle perfusion studies may be further improved by (i) incorporating a data correction procedure when air-cuff induced effects are detected; or (ii) using other gases (e.g. N_2) or water instead of air for cuff inflation to minimize local susceptibility effects.

References: 1. Ledermann HP, Schulte AC, Heidecker HG, et al. Circulation. 2006;113:2929-2935. **2.** Klarhöfer M, Madörin P, Bilecen D, et al. J Magn Reson Imaging. 2008;27:1169-1174. **3.** Bitter F. The Magnetic Susceptibility of Gases I. Pressure Dependence. Physical Review. 1930; 35:1572-1582. **4.** Cai J, Wang L, Wu P, et al. Journal of Magnetism and Magnetic Materials. 2008, 320:171–181.