Observing the settling of blood in the supine resting condition in the peripheral vascular system using SWI

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Introduction: Deep venous thrombosis (DVT) affects a large fraction of the population over 60 years of age, especially for those who are immobile for more than 4 hours, in bed, in a car or on an airplane. A recent publication has shown, for 2000 age matched spouses, that the probability of developing a DVT was more than 5% (1). The source etiology of DVT remains occult today. The goal of this study was to investigate the probable settling of blood as a potential cause for the development of local wall bearing clots which may in turn lead to DVT.

Materials and Methods: Susceptibility weighted imaging (SWI (2)) was run on the peripheral vascular system in a series of 10 volunteers. Many of these were run originally to obtain phase measurements to ascertain the local oxygen saturation. Three were run specifically to test the settling of blood. All three were part of a single family, with a child, parent and parent's brother aged 18, 52 and 56 years, respectively. Imaging was done on a 1.5T Siemens Sonata using a transmit/receive knee coil (Siemens, Erlangen, Germany) and data was acquired from the region belowe the knee, at the level of the popliteal trifurcation, with slices oriented perpendicular to the direction of flow. A high resolution SWI scan (taking 8 minutes) was run several times on each subject. The imaging parameters for this sequence were: TE = 10.2ms, TR = 21ms, FA = 15^o, resolution = 0.5 mm x 0.5 mm x 2mm, with a 512 x 512 x 64 matrix size. The scans were repeated with the read and phase encoding directions switched to rule out the possibility of flow artifacts affecting the homogeneity of phase in the vessels. In the case of the parent, the study was repeated with that subject placed in a prone position within the magnet. The phase in the veins from the high pass filtered phase images from SWI data was then carefully studied.

Results: The parent/child relationship was most revealing for the effects of changes in flow and vessel size. Swapping read and phase encoding had no effect on the phase images (as expected since the sequence is fully flow compensated). Phase response was reasonably uniform for the child and initially for the parent as well. However, after 20 minutes in the magnet, the parent's venous signal dramatically changed (see Fig. 1). When the parent was taken out and imaged again in the prone position, the vessels that had the most inhomogeneous response at the later times in the supine position now became again, clearly outlined and had a more uniform response in the prone position. However, after waiting for about 20 minutes, the low phase region which was seen at the bottom end of the vessel (towards the ground) in the supine position switched to the top of the vessel in the prone position (again towards the earth), indicating that this was an effect of gravity (see Fig. 1b). The layered phase appearance of the vessels in Fig. 1a, particularly in the supine position, demonstrates that the source of signal variation is likely due to settling of the blood. We also found that the vessels in the parent were twice as large as those in the child and therefore it can be expected that the peak velocity would be nearly four times less in the parent. The phase images reveal that some vessels appear to be "half full" with very low phase in the lower part of the vessel.

Discussion and conclusion: SWI revealed signal and phase artifacts in both phase and magnitude images that can only be explained by the settling of the blood. The larger vessels in the older adults causes a dramatic reduction in the peak speeds of the veins. This slow peak speed would allow the blood to settle in the adult but not in the child. These variations in signal intensity may explain the rather low T2* values often seen in some subjects. The expected phase for a vein parallel to the field for an oxygen saturation of about 70% and Hct of 45% should be about $\pi/4$. The phase in the lower part of the vessel showing the blood separation was in fact $\pi/2$ which would make sense only if that region was pure hematocrit. The separation of blood in the resting condition seen here may be an indication as to why people who are at rest for long periods of time develop clot and DVT. Further work needs to be done to more definitively test this hypothesis. In summary, we have shown for the first time a possible transient settling of blood in the leg for subjects in a prolonged resting condition which could point to the probable mechanism of development of deep vein thrombosis.

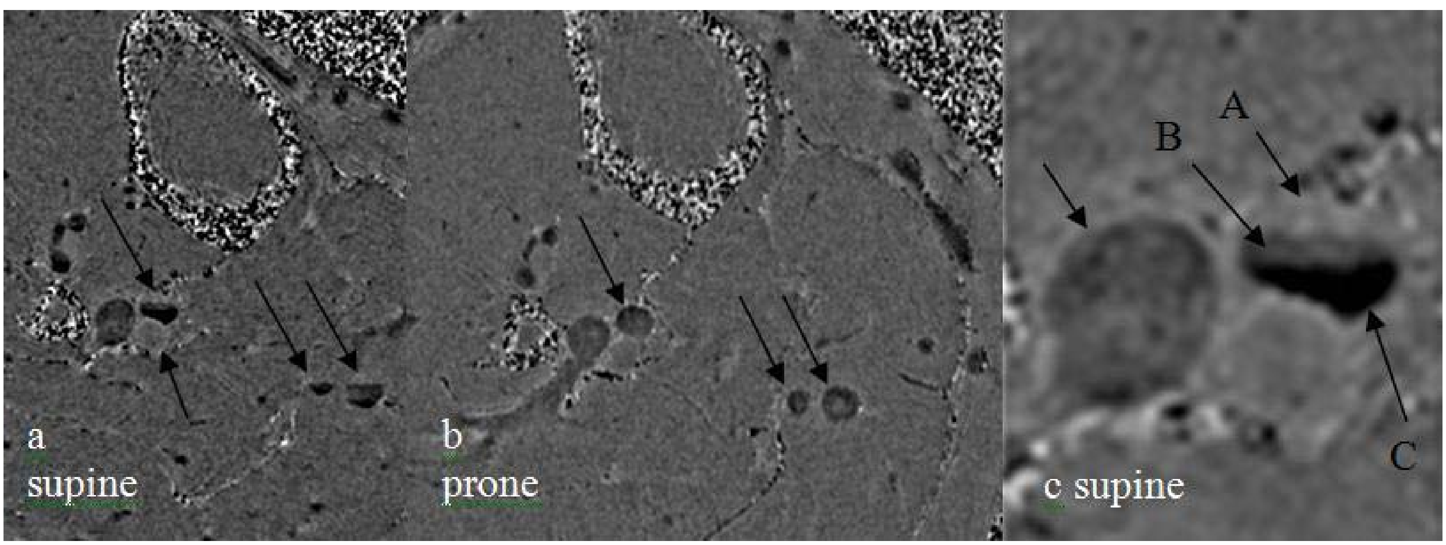

Figure 1: Both (a,c) reveal the critical separation of the blood pool into either two or three components. This is more clearly shown in the further zoomed image (by a factor of 8) in (c). Something that must be akin to water (plasma) in the topmost layer (arrow label A) as it is hard to separate from muscle; a second layer showing some susceptibility effect (arrow label B) which may be normal mixed blood; and a third layer with a strong phase change (arrow label C). The three downward pointing arrows in Fig. 6a point to three of the veins that are affected in the supine resting condition but are completely visible (and circular in cross section) in the prone position. Note that in Figure 6b (prone position) the darkening now appears at the top of the vessels as only minor settling appears to have taken place. The vessels are clearly circumscribed in the prone position but their boundaries are difficult to see in the resting supine position. As a side note, the unlabeled upward pointing arrow in Fig. 6a and 6c shows the vessel wall of the artery at the bottom and top of the vessel, respectively, making it possible to more clearly separate the artery from the vein.

References: (1) Cannegieter et al. PLOS Medicine 3; 1258, 2007. (2) Reichenbach et al. Radiology 204; 272, 1997.