Femoral Artery Compression in the Adductor Canal During Isometric Thigh Contraction using a Rapid 3D Steady-State Free Precession Acquisition

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INTRODUCTION The adductor canal is a prevalent site for peripheral arterial disease[1]. Artery curvature and stress from surrounding muscles are hypothesized to increase the frequency of disease at this site[2]. Previous work demonstrated that voluntary isometric thigh contraction compresses the femoral artery in the adductor canal, while intermuscular septa and adipose tissues may alleviate artery compression in the popliteal fossa[3]. The former report was limited to artery analysis at two discrete locations using 2D images and required two separate thigh contractions, potentially leading to less accurate results due to slice misregistration and inconsistently applied forces. Here, our objective was to image a long section (15-20 cm) of the femoral/popliteal artery in a single scan, thus eliminating variation in contraction force. A rapid 3D steady-state free precession (SSFP) sequence was implemented to visualize the artery in a short scan time necessary to minimize motion artifacts during isometric thigh contraction.

MATERIALS AND METHODS 11 healthy volunteers (6 female, age=27 ± 4 years) were imaged on a 1.5T GE Excite HDx scanner. Signal reception was provided by a flexible four channel phased-array coil (each element 14 cm L/R × 20 cm S/I) wrapped around the right leg, covering from the knee to the mid-thigh. A reference scan was performed during thigh muscle relaxation using a 3D SSFP sequence with the following typical imaging parameters: axial slices, TE=1.4 ms, TR=3.9 ms, FA=60°, FOV=20 cm, matrix=256×256, NEX=0.5, slice thickness=4 mm, parallel reduction factor=1.5, centric view ordering, and peripheral gating. A non-selective ("hard") RF pulse was used to provide a uniform excitation profile across the region of interest covered by the coil. Acquisition time was approximately 22 sec for a nominal heart rate of 60 bpm. This scan was then repeated during maximal voluntary isometric thigh contraction.

In each slice, the artery cross section was outlined using the Canny edge detection method (MATLAB), and an ellipse was fit to the artery edge using the method of least squares[4]. Axial pressure on the artery can be calculated according to $P \propto \sqrt{(a/b)} - 1$ where a and b are the lengths of the major and minor axes of the best fit ellipse and the artery's natural cross section is assumed to be a circle[5]. It was also assumed that the artery axis was normal to the imaging plane.

Anatomical landmarks were used to account for variable thigh length among volunteers. Specifically, thigh length was normalized such that the condyle corresponded to distance d=0 and the femoral head corresponded to d=1. Data was interpolated to 100 points in this range and at each point the paired student's t-test was used to determine the significance of artery pressure change between relaxed and contracted muscle states.

RESULTS Compression of the femoral artery was observed with isometric contraction (see Figs. 1 and 2) with a significant (p<0.05) increase in external artery pressure over the range d=0.19 to d=0.37 (85 mm to 166 mm superior to the condyle) which roughly corresponds to the adductor canal region. The average distance from condyle to femoral head was 448 ± 36 mm. Fig. 2 illustrates the overall muscle action (a) and artery compression in the adductor canal (b). In contrast, the artery was less compressed in regions inferior and superior to the adductor canal (Fig. 2 c,d). Images showed the artery was 14 ± 4° and 10 ± 4° out of the L/R and A/P planes, respectively, justifying the assumption that the artery was normal to the imaging plane.

DISCUSSION AND CONCLUSIONS Rapid 3D SSFP characterized the femoral/popliteal artery geometry over a long segment during isometric thigh contraction without motion artifacts. Sufficient resolution was provided to visualize the changes in artery shape, which is approximately 6 mm in diameter during relaxation. In the adductor canal, the femoral artery is located in a relatively narrow space between the posterior region of the vastus muscle and anterior region of the hamstring muscle group. During isometric contraction, the vastus muscle expands posteriorly and the hamstring expands anteriorly. Together, these muscles act to compress the artery. The frequent occurrence of atherosclerotic disease there suggests repetitive vascular compression contributes to atherosclerosis. Inferior to the adductor canal, the distance between the two muscle groups is greater where intermuscular septa and adipose tissues protect the artery even though there is flexion at the knee joint. This technique may be useful for identifying individuals at high risk for adductor canal disease.

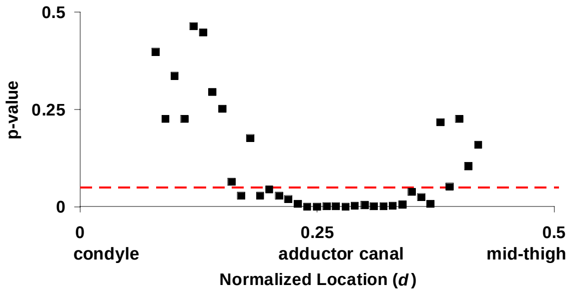
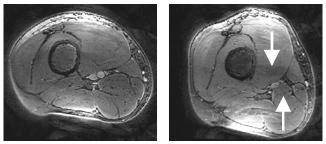
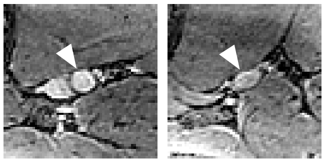


Fig. 1. p-value plot as a function of location along the thigh illustrates that the femoral/popliteal artery experiences a significant change in external pressure during isometric thigh contraction in a region corresponding to the adductor canal. The p=0.05 significance level is shown.



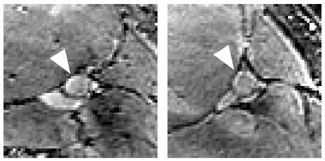
Relaxed, P=0.05 Contracted, P=0.20

a d=0.32, adductor canal region



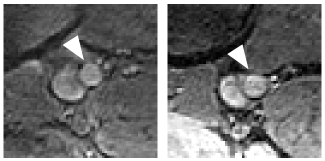
Relaxed, P=0.05 Contracted, P=0.20

b d=0.32, adductor canal region



Relaxed, P=0.10 Contracted, P=0.09

c d = 0.42, superior to adductor canal



Relaxed, P=0.07 Contracted, P=0.08

d d = 0.21, inferior to adductor canal

Fig. 2. Images show the thigh in the relaxed (left column) and contracted (right column) states. Full FOV images (a) illustrate the overall action of the vastus and hamstring muscles (arrows). Arrow heads in the zoomed images (5x5cm^2) illustrate artery compression in the adductor canal during isometric contraction (b), while the artery is less disturbed in regions superior (c) and inferior (d) to the canal. Normalized thigh location d and external pressure P are given for each image.

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