Superficial Femoral Artery Deformations Due to Maximal Hip and Knee Flexion: Implications for Stent Design

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Introduction

Stenoses in the superficial femoral artery (SFA) are often treated with percutaneous transluminal angioplasty and stent deployment [1]. Recently, studies estimate that stents in the SFA fracture at a rate of 15 to 20%, and that these fractures are highly correlated to restenosis and the return of clinical symptoms [2, 3]. While stent fractures have been reported in other vessels, it is hypothesized that the SFA may experience them with greater frequency due to dramatic non-pulsatile deformations in the adductor canal including axial compression and extension, radial compression, bending, and torsion [2, 4]. While these deformation modes of the SFA have been hypothesized, no studies have quantified these deformations *in vivo*. We report the deformations of the SFA in four healthy subjects (eight limbs) between supine (zero hip and knee flexion) and fetal (maximal hip and knee flexion) positions using a 3D MRA and geometric modeling approach.

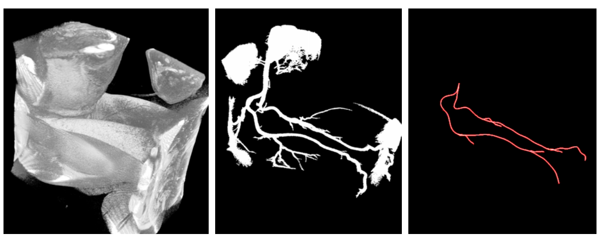
Methods

Contrast-enhanced MRA was performed on four healthy volunteers (20-30 years) in the supine and fetal (left decubital) positions using a GE Signa Excite 1.5T scanner. The imaging protocol was approved by the Stanford University Panel on Human Subjects in Medical Research and written consent was obtained from each volunteer. MRA imaging volumes were prescribed to encompass both lower extremities from the level of the iliac arteries to the knees. Gadolinium injection was administered through an intravenous catheter line to the antecubital vein at a rate of 3 ml/sec with a total of 0.1 mmols/kg of contrast (approximately 20 cc) for each of the two scans. The gadolinium contrast was injected according to real-time flouro triggering, approximately 20 seconds before the scan such that the center of the bolus reached the region of interest during acquisition of the center of k-space. A 3D gradient-recalled echo MRA sequence was performed in approximately 40 seconds with the following parameters: 5.1 ms TR, 1.2 TE ms, 25 degree flip angle, 448 by 256 acquisition matrix for each slice, and 3 mm slices with 1.5 mm overlap.

From the gradient warping-corrected [5] MRA volume data, centerline spline paths for the iliofemoral, profunda femoris, and descending genicular arteries were constructed for each limb using custom software (Figure 1) [6]. We define the SFA segment of interest to be the length of the femoral artery between the profunda femoris and descending genicular arteries. Arc lengths for the SFA centerline splines were computed between the two branches for both body positions and for each limb. In addition, the angle of branching separation off of the main axis of the SFA between the two branches was quantified. SFA arc length change and angle twist (using the profunda femoris as the reference branch) could subsequently be calculated between supine and fetal positions.

Results

All four subjects were flexible enough to fit inside the scanner bore in the supine and fetal positions, and the 3D images were of sufficient quality to identify paths for the arteries of interest. Arc lengths of the SFA for each limb are shown in Table 1, along with SFA stretch and angle of twist from supine to fetal positions. Anatomic variation between subjects was visually noticeable in both body positions. Three out of four subjects exhibited SFA elongation from supine to fetal positions, while one subject experienced SFA shortening (stretch range: left SFA = -7% to 26%, right SFA = -21% to 25%). In addition, three out of four subjects exhibited counterclockwise twist in the right SFA and clockwise twist in the left SFA from supine to fetal positions, while one subject experienced opposite twist directions (angle of twist range: left SFA = 89° CW to 119° CCW, right SFA = 58° CCW to 50° CW). Although the magnitude of strain and twist differed between the left and right SFAs of individuals, the direction of deformation was consistent within individuals.



A B C

Figure 1. (A) Volume-rendering of a 27 y.o. healthy male subject in the fetal position in a GE Signa Excite 1.5T scanner. (B) Thresholded point cloud of the gadolinium-enhanced MRA of the lower extremity vasculature. (C) Corresponding centerline paths of the iliofemoral artery and the profunda femoris and descending genicular artery branches.

Table 1. SFA Measurements and Deformations

	Arc Length (cm)			
	Supine	**Fetal**	**Stretch**	**Twist**
A – Left	17.8	22.5	26%	89° CW
A – Right	16.8	21.0	25%	58° CCW
B – Left	20.3	22.4	11%	119° CCW
B – Right	19.7	20.9	6%	50° CW
C – Left	24.1	25.1	4%	105° CCW
C – Right	24.0	24.5	2%	38° CW
D – Left	19.7	18.4	-7%	69° CCW
D – Right	21.4	16.8	-21%	12° CW

Arc lengths of the superficial femoral arteries (SFA) of eight limbs (four subjects, identified by A, B, C, D) in the supine and fetal positions. Stretch of the SFA from supine to fetal position is shown in column 3 (positive = elongation, negative = shortening). Twist of the SFA from supine to fetal position, using the profunda femoris artery as the reference branch, is shown in column 4 (CW = clockwise, CCW = counterclockwise).

Discussion

While people do not spend most of the day statically in the supine position, our knowledge of vascular anatomy is largely limited to this body position. It has been hypothesized that the high rate of SFA nitinol stent fracture (~19%) is related to the dramatic, repetitive deformations that occur in the SFA due to lower extremity movement [2]. This is the first study that quantifies SFA deformations *in vivo* in humans due to different body positions.

We found that the SFA elongates, shortens, and twists substantially and variably in the eight limbs of four healthy subjects due to maximal hip and knee flexion. Out of eight SFAs, the greatest elongation was 26% and the greatest shortening was 21%. Angle of twist also varied greatly between individuals and between limbs intra-individual, and the direction of twist was even different between subjects. These stretch and twist variations are likely related to anatomic variations in SFA location with respect to the hamstring and quadriceps muscles, locations of the profunda femoris and descending genicular branches on the SFA, lines of action of the muscles neighboring the SFA, and the geometry of the hip and knee joints. The variation between subjects necessitates that stents need to be able to survive in very dynamic and unpredictable environments. In fact, as these deformations are likely localized, rather than uniform along the length of the SFA, stents in particular locations may need to be more durable than in other locations.

The deformation data acquired in this study has the potential to help elucidate stent fracture mechanisms in the SFA as well as describe mechanical loading boundary conditions to guide the design of future stents and develop mechanical fatigue tests. While gross measurements of stretch and twist can be made with the described techniques, it will be important to develop methods to identify more precise, spatially-resolved deformations in the future.

Acknowledgements

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