Effect of Stent Implantation on the Deformations of the Superficial Femoral Artery and Popliteal Artery: In Vivo Three-Dimensional Deformational Analysis from Two-Dimensional Radiographs

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ABSTRACT

The objective of this work was to develop a system for three-dimensional (3D) reconstruction of the femoropopliteal artery from two angiographic views and to quantify the in vivo 3D deformations in 18 patients before balloon angioplasty and after primary stent implantation. The procedure had an insignificant effect on the bending behavior of the artery, as the average mean curvature change within the lesion remained constant before (0.04 cm^{-1} ± 0.03) and after stent implantation (0.03 cm^{-1} ± 0.04). A significant effect of stent implantation was measured in terms of a decrease in arterial shortening during leg flexion.

ABBREVIATIONS

SFA = superficial femoral artery, 3D = three-dimensional, 2D = two-dimensional

Stent fractures have been frequently associated with arterial deformations (1,2), but the effect of fractured struts on in-stent restenosis is controversial (3,4). Even though improved stent design has significantly decreased the occurrence of stent failure, changes in the mechanical environment distal or proximal to the stent-implanted arterial segment could lead to arterial kinking and chronic trauma. This effect might be one explanation for the high restenosis rates observed in the femoropopliteal arteries (5).

Quantification of arterial deformations following primary stent implantation is required to understand the relationship between the mechanical environment and high restenosis rates observed in the stent-implanted femoropopliteal artery. Several groups have proposed methods to assess the dynamic conformational changes of the artery during leg movement (6–9). With the exception of one (6), these studies failed to characterize the arterial deformations on stent-implanted arteries in vivo, and none described the deformations of bare arteries in close vicinity of the stent-implanted segments.

Therefore, the objective of the present study was to estimate the in vivo deformational changes of the femoropopliteal artery before balloon angioplasty and after primary stent implantation. Two angiographic images of the leg in straight and flexed positions were used to determine a three-dimensional (3D) representation of the arterial tree. The resulting patient-specific 3D representations were subsequently aligned, and the changes in length and curvature were measured.

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MATERIALS AND METHODS

Angiography

Eighteen patients (12 male; mean age, [mean ± SD] 68 y ± 8.6) scheduled for peripheral arterial disease treatment were recruited for this study. Institutional review board approval was obtained by the Kantonsspital Aarau (Aarau, Switzerland). The study was performed in accordance with the Declaration of Helsinki, and informed consent was obtained from all individual participants.

For each patient, a series of angiographic images were acquired as part of the normal clinical routine. Before balloon angioplasty and after primary stent implantation, angiographic images were acquired with an Allura FD 20 Xper X-ray system with Clarity Upgrade (Philips, Best, The Netherlands) and recurrent injection of contrast agent. During the intervention, the balloon was inflated to approximately 10 atm. Following balloon angioplasty of the arterial lesions, 15 patients underwent placement of one self-expanding nitinol stent, whereas three patients received two stents each (**Table 1**). The lengths and types of the stents were selected by the operator based on the lengths, morphologies, and locations of the lesions. The patients were adjusted in supine position, and angiographic images of the straight and flexed leg (hip/knee flexion of 20°/70°) were obtained. The acquired subtraction angiographic and cine images were stored on the workstation. To determine the spatial relationship between the angiographic images, a small-sized calibration object was attached to the patient's thigh with a strap (10).

Three-Dimensional Model Reconstruction

The 3D reconstruction of the arterial tree relied on a pair of angiographic images, which were interactively selected among the series of images, with a view angle greater than 25°. For each image, the two-dimensional (2D) boundaries of the main branch were semiautomatically outlined by using a live-wire algorithm (11). In addition, points along the centerlines of a certain number of side branches were interactively chosen (**Fig 1**). The extraction of corresponding sections was thereby guided by the visualization of epipolar lines (12). The uniformly interpolated boundaries of the main branch, together with the particular calibration information, were then used to perform a straightforward multiview reconstruction as, for example, described by Movassaghi et al (13). The side branches were reconstructed in the same way. As only centerline points were defined for the side branches, the particular points were directly triangulated. A surface model of a reconstructed arterial tree is shown in **Figure 1**.

Reconstruction Analysis

To analyze the multiview reconstruction capability, the forward and backward projection accuracy of the arterial tree was assessed with respect to an additional validation view. This validation view was also interactively selected, with a view direction that had to be different (at least 20° apart) than the two views used for 3D reconstruction. The forward projection error was calculated as the average error distance between the

Table 1. Patient Demographics, Level of Calcification, and Description of Lesions and Implanted Stents

		Lesion		Implanted Stents	
Pt. No./Age (y)/Sex	**Calcification Level**	**Location**	**Length (mm)**	**Type**	**Size (mm)***
1/65/M	Moderate	Mid-/distal SFA	60	Pulsar 18	6 × 40
2/75/M	Moderate	Distal SFA/popliteal	180	Pulsar 18	6 × 200
3/56/M	Moderate	Mid-/distal SFA	50	Xpert	4 × 40
4/68/F	Moderate	Mid-SFA	60	Zilver PTX	5 × 80
5/66/F	In-stent reocclusion	Proximal/mid-SFA	200	EverFlex	5 × 150
6/75/M	Severe	Mid-/distal SFA	180	EverFlex	6 × 200
7/79/F	Severe	Proximal/distal SFA	350	Pulsar-18 (×2)	5 × 200
8/71/M	Severe	CFA/distal SFA	350	EverFlex (×2)	6 × 200
9/66/F	Moderate	Proximal/distal SFA	300	Pulsar-18	5 × 200
10/76/F	Severe	Proximal/distal SFA	400	EverFlex (×2)	6 × 200
11/65/M	Moderate	Distal SFA	100	Zilver PTX	6 × 120
12/71/M	Moderate	Mid-/distal SFA	100	Zilver PTX	6 × 120
13/81/M	Moderate	Popliteal	70	Pulsar-18	5 × 80
14/48/M	Severe	Mid-/distal SFA	50	EverFlex	6 × 60
15/79/F	Severe	Mid-SFA	80	EverFlex	5 × 100
16/61/M	Moderate	Mid-SFA	100	Zilver PTX	5 × 120
17/62/M	Moderate	Proximal/mid-SFA	300	EverFlex	6 × 200
18/65/M	Moderate	Distal SFA	100	Zilver PTX	6 × 120

CFA = common femoral artery; SFA = superficial femoral artery.
*Presented as diameter × length.

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