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A method to determine the radial compliance of porcine coronary arteries *ex vivo* via optical coherence tomography

Abstract: Optical coherence tomography (OCT) as imaging method is widely used in ophthalmology, oncology and cardiology. For intravascular imaging the OCT is used for pre-interventional as well as post-procedural assessments. Within the current study a test setup for *ex vivo* determination of the compliance of porcine coronary arteries via OCT is described. Diameter measurements based on OCT imaging were performed during consecutive pressurization of a porcine coronary artery from 40 to 200 mmHg in a physiological environment. The test results indicate that the radial compliance depends on the specific segment of the artery as well as the pressure range considered. The revealed compliance data can be used for numerical simulations of the vascular tissue as well as for optimization of *in vitro* test setups for pulsatile testing of vascular implants.

Keywords: Radial compliance, optical coherence tomography, OCT, coronary artery, ex vivo

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1 Introduction

Quantification of the mechanical properties of vascular tissue, such as the radial compliance represents an essential requirement for the implementation of effective *in vitro* testing methods, e.g. for pulsatile durability testing of vascular stents [1].

Measurements of the radial compliance based on Intravascular Ultrasound (IVUS) are well documented [2-4], but limited due to low spatial resolution.

Optical coherence tomography (OCT) as medical imaging method was first used in ophthalmology in 1991 for imaging of the retina. Since then, OCT was established as medical imaging method for various applications in ophthalmology, oncology and cardiology [5]. In general, OCT detects the reflections of the emitted near-infrared light (wavelength 1.3 µm) and generates a sectional image of the investigated sample based on the duration of the light waves (A-line) [6]. For intravascular imaging the rotating optic in the distal tip of a special OCT catheter is used to obtain a cross sectional image generated from the circumferential recorded A-lines [7]. A 3D-image is revealed combining the recorded cross sectional images from a defined longitudinal pullback of the catheter. Imaging of the intravascular structure is generally used for pre-intervention assessment (localization and morphology of the lesion) as well as post-procedural assessments (lumen measurements, assessment of wall apposition of stent struts and identification of complications) [6]. Due to the high spatial resolution of 5 – 15 µm [6, 8], OCT is suitable for precise measurements of the intraluminal diameter of coronary arteries.

The aim of the current study was to develop a test method for determination of the compliance of porcine coronary arteries *ex vivo*. Therefore, OCT was used to measure the intraluminal diameter of the arteries at defined intra-arterial pressure levels.

2 Materials and methods

A porcine heart was obtained from the Leibnitz Institute for Farm Animal Biology (Dummerstorf, Germany). During transport, preparation and measurements the porcine heart was stored in phosphate buffered saline (PBS, Carl Roth GmbH & Co. KG, Karlsruhe, Germany) to maintain physiological conditions. Access to the coronary arteries was prepared by resection of the aorta down to the coronary sinus ostium. Then, a Luer-tube connector was fixed inside the

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very proximal region of the left anterior descending coronary artery (LAD) with the help of surgical sewing material. A haemostatic Y-valve was used to allow the introduction of an OCT catheter into the LAD as well as to apply a steady media flow through the LAD. Leakage through the myocardium was reduced by sealing large arterial endings with super glue. As a result, a stepwise static pressure could be generated within the LAD by adjusting the flow rate of the media. The pressure was measured by an analogous pressure sensor 86A (Measurement Specialities, Inc., Hampton, VA USA) in a custom made housing with a measurement uncertainty of 3 % within the measurement range from 0 to 258 mmHg [9, 10]. The OCT catheter (Dragonfly OPTIS Imaging Catheter, Abbott Medical, Westford, MA, USA) was placed distal inside the LAD. The LAD was pressurized consecutively in the pressure range of 40 to 200 mmHg (40, 80, 100, 120, 160, 200, 160, 120, 100, 80, 40 mmHg) and a pullback OCT measurement (54 mm, 10 frames/s) was performed at every pressure state. OCT data acquisition and data evaluation was performed with the ILUMIEN OPTIS PCI Optimization system (St. Jude Medical, Saint Paul, MI, USA). A schematic overview of the test setup is presented in Figure 1.

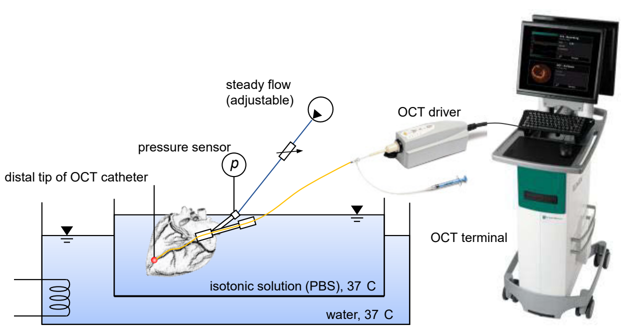

Figure 1: Test setup for determination of the radial compliance of porcine coronary arteries with optical coherence tomography

The mean lumen diameter was directly calculated from the determined lumen area of each cross sectional image. The arterial compliance was determined for physiological (120/80 mmHg) and a hypertension pressure range (160/100 mmHg) according to equation 1 [1].

$$C = \frac{d_{syst} - d_{diast}}{d_{diast}} \cdot \frac{1}{\Delta p} \cdot 10^4 \ [\%/100 \text{ mmHg}] \qquad (1)$$

For calculation of the arterial compliance five to six diameter measurements were averaged for each the distal, middle and proximal portion of the investigated LAD section at the specific pressure steps.

3 Results

An exemplary longitudinal OCT-image of the examined LAD at an intra-arterial pressure of 120 mmHg is presented in Figure 2. Regions with side branches were excluded from the evaluation.

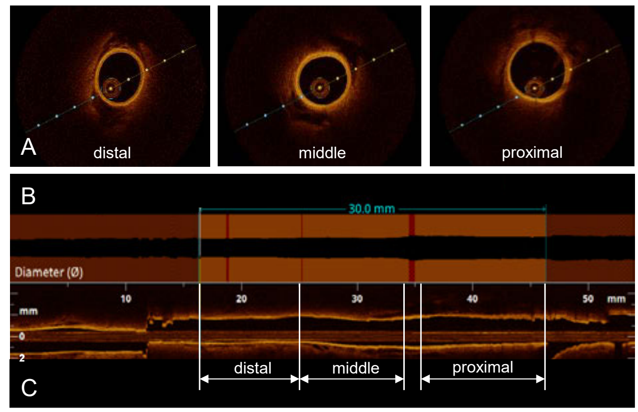

Figure 2: Cross-sectional OCT images (A), lumen profile (B) as well as longitudinal OCT image of the investigated LAD at an intra-arterial pressure of 120 mmHg

The averaged intraluminal diameters as measured with OCT for all pressure steps are illustrated in Figure 3.

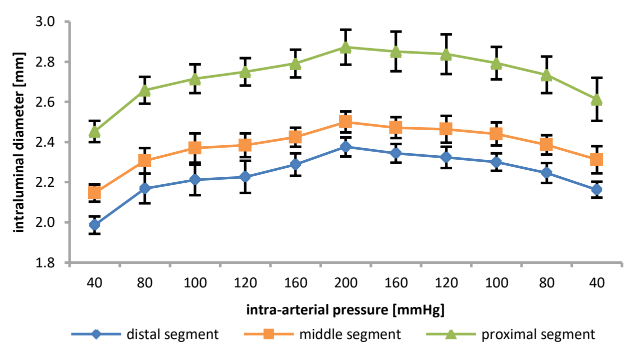

Figure 3: Intraluminal diameter as a function of the intra-arterial pressure in different arterial segments; mean value ± standard deviation (n = 5 for distal and middle segment, n = 6 for proximal segment)

The intraluminal diameter increases with intra-arterial pressurization and decreases with pressure reduction. The measured diameter at the beginning and the end of the cycle (40 mmHg) differed by 0.16 - 0.18 mm. The mean diameter at every pressure step was largest for the proximal segment and smallest for the distal segment.

The specific diameters used for the calculation of the elastic radial compliance and the calculated compliances are given in Table 1. The calculated radial compliances ranged from 3.8 – 8.6 %/100 mmHg depending on the considered pressure range and the considered segment (see also Figure 4).

Table 1: Diameter values d (mean value ± standard deviation) as well as the calculated radial compliances C for the distal segment (DS), the middle segment (MS), the proximal segment (PS) as well as the complete segment (CS) at different pressure steps or pressure intervals, respectively (subscripts refer to pressure in mmHg)

		DS (n=5)	**MS** (n=5)	**PS** (n=6)	**CS** (n=16)
d_{80}	[mm]	2.168 ± 0.073	2.306 ± 0.063	2.658 ± 0.067	2.395 ± 0.227
d_{100}	[mm]	2.212 ± 0.076	2.370 ± 0.073	2.715 ± 0.071	2.450 ± 0.232
d_{120}	[mm]	2.226 ± 0.080	2.384 ± 0.059	2.750 ± 0.068	± 2.472 ± 0.241
d_{160}	[mm]	2.288 ± 0.056	2.424 ± 0.047	2.792 ± 0.069	2.574 ± 0.238
$C_{120/80}$	[%/100 mmHg]	6.69	8.46	8.62	8.02
$C_{160/100}$	[%/100 mmHg]	5.73	3.80	4.71	4.72

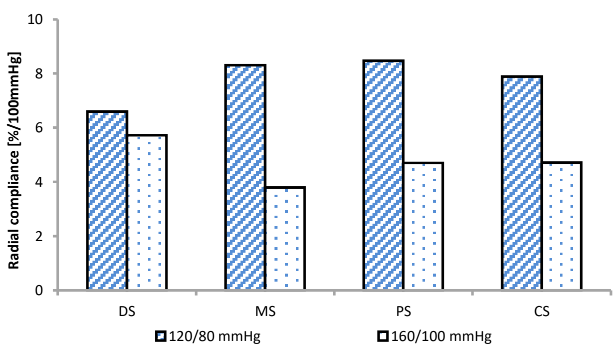

Figure 4: Radial compliance for the physiological and hypertension pressure range for the distal segment (DS), the middle segment (MS), the proximal segment (PS) as well as the complete segment (CS)

4 Discussion

The current study presented a method for the determination of the radial compliance of porcine coronary arteries via OCT *ex vivo*.

Diameter measurements could be performed with a high accuracy due to the high resolution of the OCT images (± 15 µm) [11]. The test setup up, which was built up in accordance to the clinical use allows for reproducible measurements. Advantageous for the OCT measurements was the use of PBS as test medium, which enables permanent measurements.

The different diameters of the classified artery segments (2.0 – 2.4 mm for the distal segment, 2.1 to 2.5 mm for the middle segment and 2.5 to 2.9 mm for the proximal segment) reflect the tapered anatomy of a coronary artery from proximal to distal [12].

The diameter difference of 0.16 – 018 mm between the beginning and the end of the measurement cycle may imply a damage of the vascular tissue or reflects the viscoelastic properties of the arterial wall [13].

The radial compliance was higher for the physiological pressure range of 120/80 mmHg (6.7 – 8.6 %/100 mmHg) compared to the hypertension pressure range 160/100 mmHg (3.8 – 5.7 %/100 mmHg). The artery is stiffer at higher internal pressures. The presented test results are in good accordance to the compliances measured with the help of IVUS (2.5 – 12 %/100 mmHg) [2-4].

The restriction to *ex vivo* measurements represents a major limitation of the presented test method. However, *in vivo* conditions were simulated as good as possible, i.e. short time period between extraction of the porcine heart and testing or the use of a physiological test medium and testing temperature. Measurements were performed within static conditions, rather than considering a pulsatile flow. Thus, dynamic effects of vascular motion were neglected.

Nevertheless, the described test method is highly reproducible, and averaging of different cross sections at the same pressure state could reduce stochastic error. Further studies should also include a higher sample size of porcine hearts and coronary arteries, respectively, as well as a larger number of diameter measurements in longitudinal direction to gain even more improved statistical significance of the test results.

The revealed compliance data of coronary arteries can be used to optimize test setups for pulsatile testing of vascular implants as well as for numerical simulations of the vascular structure.

Author Statement

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