ESRF	**Experiment title:** X-ray Microtomography of Deployment of a Cardiovascular Stent	**Experiment number**: MD-136
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Shifts: 6	**Local contact(s)**: Joanna HOSZOWSKA	*Received at ESRF:*

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Report:

The aim of the experiment was to prove the concept of using high-resolution, X-ray micro-tomography to study the deployment characteristics of a coronary stent. Coronary stents are small, metallic scaffolds implanted to re-open coronary arteries which have become narrowed or blocked as a result of heart disease. Sometimes, injury to the artery during implantation triggers an excessive inflammatory response, causing re-blockage of the artery over time. Relatively little is known about how stents interact with the artery during implantation. Imaging in three-dimensions would provide engineers and clinicians with information to help improve stent design and deployment. The motivation for using X-ray micro-tomography was that the technique has a resolution and field of view good enough to image a stent in three dimensions, so that stent-artery interactions could be observed. A typical stent has an expanded diameter of 3.0 mm and a strut width of 70-100 μm.

EXPERIMENTAL METHODS

This was an *in-vitro* study in which stents were deployed inside model arteries made from latex rubber and silicone foam, which have similar mechanical properties to natural arterial tissue. The stents used were stainless steel coronary R-stents (Orbus Medical Technologies, Inc). Figure 1 shows a stent implanted in a model artery and an X-ray projection obtained at the ESRF. Beamline BM05 at the ESRF was used, at the station ~40 m from the source. One problem to overcome was how to mount the relatively flexible mock artery vertically on the sample stage without it shifting during the tomography scan. This was solved by placing the mock artery inside a stiffer, thin walled, transparent polymer support tube. Preliminary scans were taken using beam energies from 17-25 keV. The stent struts generated strong attenuation artefacts in the reconstructed images. Artefacts were decreased by increasing the beam energy. 25keV was found to be the best compromise between field of view, artefact level and resolution. The voxel size was 5.3 μm, with a vertical field of view of 4.5 mm. for each scan 900 projections were taken at 0.2^{o} intervals. To image whole stents, which were 13 – 25 mm long, multiple scans were taken, translating the sample vertically between scans until the whole stent was imaged. Three experiments of increasing complexity were performed:

Experiment 1: 1a. Scan of a fully deployed stent in a model artery, balloon catheter removed.
Experiment 2: 2a. Scan of an undeployed stent in a model artery.
2b. Scan of the stent deployed at maximum balloon pressure and the balloon in place.
2c. Scan with the balloon deflated and still in place.
Experiment 3: 3a. Scan of an undeployed stent in a mock artery.
3b. Scan of the stent, partially deployed.
3c. Scan of the stent, fully deployed, at the nominal deployment pressure.
3d. Scan of the stent fully deployed to the balloon burst pressure, after balloon deflation.

A suitable method of supporting and securing the delivery catheter and inflation device during the scan had to be devised. Additional pieces of silicone foam were placed between the catheter and mock artery wall, to ensure the stent did not move during or between scans. These foam inserts were outside the field of view and did not interfere with stent deployment. The catheter and inflation device were suspended vertically from a gantry above the sample stage using a piece of fine cord. This arrangement meant that torsion arising from sample stage rotation was transferred to the cord, rather than the catheter.

RESULTS

The tomography data for the experiments was processed to give raw volume files readable by standard CT imaging software. For each stent there exists a complete set of slices, taken every 5.3 µm, enabling very detailed observation and measurements of stent-artery interactions possible. Figure 2 is an example slice, showing the latex tubing representing the artery wall, the stent struts and the silicone foam representing the blockage. Phase contrast makes it possible to see the foam and the deflated balloon, which was left in place for the scan. The streaks in the image are attenuation artefacts associated with the stent struts. Further analysis and measurements are in progress.

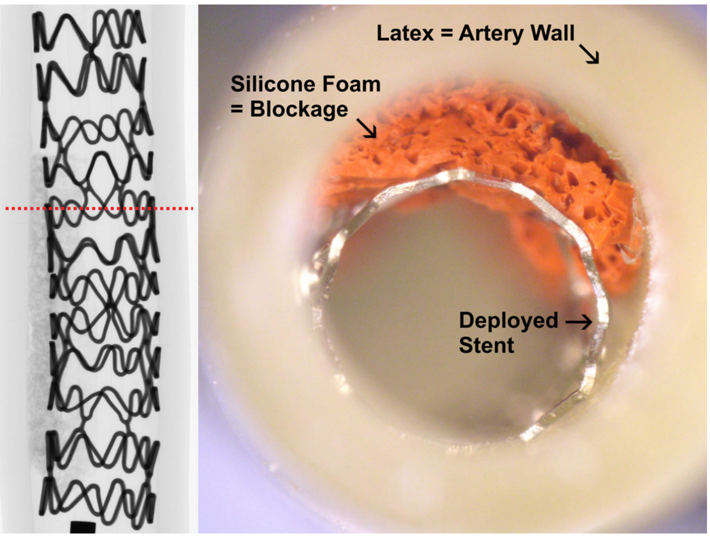

Fig. 1: Photograph of a stent implanted in a model artery. The inset on the left is an X-ray projection of the implanted stent, which is 13mm long. The dashed line shows the position of the tomography slice shown in Fig. 2.

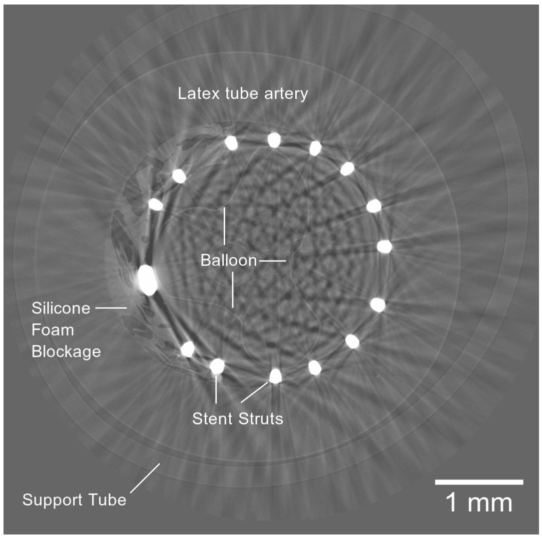

Fig. 2: Example slice from the tomography scan of the stent in Fig. 1.

CONCLUSIONS

The feasibility of using high-resolution X-ray micro-tomography to image a coronary stent in a model artery was demonstrated. The stent and artificial artery materials were imaged satisfactorily, though with some attenuation artifacts arising from the metallic stent struts. There is considerable scope to develop the technique further, including observation of real tissue samples or excised stents.

PUBLICATIONS RESULTING FROM THIS EXPERIMENT

Connolley T, Nash D, Buffière J-Y, Sharif F, McHugh PE: "X-ray micro-tomography of a coronary stent deployed in a model artery".Submitted to *Ann. Biomed. Engng.*