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Radiological methodology for quantification of thoracic aortic flow and geometry with respect to thoracic endovascular aortic repair

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Thoracic endovascular aortic repair (TEVAR) has been increasingly used for treating thoracic aortic diseases. Its major drawback is a high complication rate. The rate might be reduced by analysing postoperative haemodynamics, using advanced preoperative measurement techniques or considering aortic dynamics. The purpose of this thesis was to advance knowledge for radiological methodology for quantification of thoracic aortic flow and geometry with respect to TEVAR towards introduction into clinical practice.
Aortic flow quantification by 2D VEC MRI and 3D VEC MRI in an aortic nitinol stent graft was validated in vitro; aortic flow quantification by 3D VEC MRI was validated in vitro and in vivo. An elastic tube phantom mimicking the aorta was developed with the possibility to insert an aortic nitinol stent graft and to generate different flow patterns (constant, sinusoidal and pulsatile aortic flow). Three VEC MRI sequences were applied: two-dimensional through-plane VEC MRI (2D-TP-MRI), stacked twodimensional three-directional VEC MRI (stacked-2D-3dir-MRI) and three-dimensional three-directional VEC MRI (3D-3dir-MRI). The percentage difference of the measurement to the respective gold standard was defined as accuracy.
Accuracy of low quantification by 2D-TP-MRI in an aortic nitinol stent graft in vitro was -0.18 % (p=n.s.). It was not influenced by stent graft position. Accuracy of flow quantification by stacked-2D-3dir-MRI in vitro was -6.8 % for velocity ($p<0.001$), +13.6 % for area ($p<0.001$), and -7.4 % for flow ($p<0.001$). In vivo, stacked-2D-3dir-MRI underestimated velocity ($p<0.001$) and overestimated area ($p<0.001$ in aortic arch and descending aorta). Flow was significantly underestimated in the ascending aorta (p=0.035), but tended to be overestimated in the aortic arch and descending aorta. Accuracy of flow quantification by stacked-2D-3dir-MRI in an aortic nitinol stent graft in vitro was -5.4 % (p=0.016), by 3D-3dir-MRI -4.1 % (p=0.013). However, both stacked-2D-3dir-MRI and 3D-3dir-MRI exhibited significantly higher flow volume measurements within the stent graft compared to identical measurements without stent graft ($p<0.001$/p=0.003).
Measurement techniques for quantification of static aortic geometry in candidates for TEVAR were validated in vivo. Preoperative CT angiographies of 30 patients with thoracic aortic disease were analysed in an individually randomised order by one blinded vascular expert (reference) and three blinded non-expert readers. Aortic diameters were measured at four positions using three measurement techniques (manual axial slices, manual double oblique multiplanar reformations (MPR), semiautomatic centreline analysis). Reliability was calculated as absolute measurement deviation (AMD) from reference and interobserver variability as coefficient of variance (CV) among non-expert readers. For axial, MPR, and centreline technique mean AMD was 7.3 ± 7.7 %, 6.7 ± 4.5 %, and 4.7 ± 4.8 % and mean CV was 5.2 ± 4.2 %, 5.8 ± 4.8 %, and 3.9 ± 5.4 %. Both AMD and CV were significantly lower for centreline analysis compared to axial technique (p=0.001/0.042) and MPR (p=0.009/0.003).

Finally, normal reference values for heartbeat-related displacement of the thoracic aorta were investigated. 61 healthy volunteers divided into two age groups (A: <50, B: ≥50 years) underwent dynamic MRI. Aortic centre of mass (CoM) displacement was determined at five locations of the thoracic aorta as percentage of diastolic aortic diameter. A multiple linear regression model including age group, gender, location, mean arterial blood pressure, heart rate and body mass index was tested.
Mean aortic displacement averaged over all locations was 15.1 ± 8.3 % (age group A) and 11.0 ± 6.2 % (age group B). Systolic and diastolic CoM position significantly differed at all locations ($p<0.001$). Displacement could be predicted based on the regression model ($p<0.001$). Age group A and women exhibited significantly greater displacement compared to age group B ($p<0.001$) and men ($p<0.01$), respectively.
Flow quantification by 2D VEC MRI within an aortic nitinol stent graft may give new insights into the haemodynamic consequences of TEVAR and could be used to validate computational simulations. 3D VEC MRI may give a comprehensive insight into aortic haemodynamics prior to and after TEVAR, but flow quantification must be interpreted with care regarding the current limitations. Semiautomatic centreline analysis should be the preferred measurement technique for non-expert readers. MPR remains an important alternative if centreline analysis is not successful, but should be performed by expert readers. Clinical predictors for increased aortic displacement such as female gender and age below 50 can help to identify individuals at risk for extensive displacement. Extensive displacement may have relevant consequences for the outcome of TEVAR in previously healthy patients e.g. with traumatic aortic transection, especially regarding stent graft durability, sealing and stent graft dislocation.
Overall, this doctoral thesis successfully advanced the knowledge for several radiological methodologies for quantification of thoracic aortic flow and geometry with respect to TEVAR. Fundamental and experimental research was conducted to form the basis for future introduction of the presented radiological methodology into every day clinical practice. The presented radiological methodology promises improvements for preoperative planning of TEVAR as well as postoperative surveillance, and thereby may reduce the incidence of postoperative complications.