Moving shear stress towards the clinic: preclinical comparison of optical coherence tomography-based versus angiography-based time-averaged wall shear stress estimations

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Introduction: Identification of coronary atherosclerotic plaques at risk of causing future acute coronary syndromes remains a major unmet clinical challenge. The addition of vessel biomechanics to intracoronary imaging derived evaluation of plaque morphology, improves identification of plaques likely to develop high risk features. We and others have developed a framework for intracoronary imaging (optical coherence tomography [OCT]) based 3D reconstructions of coronary arteries for computational fluid dynamics (CFD) simulations of shear stress, which are considered the current gold standard approach for quantification of coronary arterial haemodynamics. However, these approaches are time consuming and computationally intensive, resulting in a barrier to clinical uptake.

Purpose: Determination of time averaged wall shear stress (TAWSS) based on 3D coronary geometries from non-invasive 3D Quantitative Coronary Angiography (3D-QCA) has recently been developed (Pie Medical Imaging, Netherlands), which enables results of shear stress simulations to be available within 30 minutes. We sought to compare TAWSS determined from 3D-QCA with gold standard OCT-based CFD simulations in both normal and stenotic arteries in minipigs.

Methods: 15 normal and 5 stenotic minipig coronary arteries were studied. Anatomically matched 3D arterial geometries were reconstructed from 3D-QCA and OCT using common centrelines. Boundary conditions for simulations included directly measured inlet blood velocities; parabolic inlet flow profiles, zero pressure outlet; no-slip arterial walls; blood density: 1.05 g/ml; blood dynamic viscosity: 0.035 g/cm.s. Blood was modelled as Newtonian. 3D-QCA TAWSS was obtained with a Kratos Multi-Physics CFD solver. OCT-based simulations were performed using Abaqus/CFD v6.14. TAWSS was calculated for 80 axially matched segments for both methods (1200 and 400 paired comparisons for normal and stenotic arteries, respectively). Data were analysed using Bland-Altman and Wilcoxon matched-pairs signed ranked tests.

Results: Computation times for 3D-QCA and OCT-based CFD were approximately 30 minutes and 2 hours respectively. Axial profiles of TAWSS were similar between the two methods and there was agreement in TAWSS magnitudes and narrow 95% limits of agreement (Figure 1 and Figure 2). Using co-registered TAWSS maps generated by each method, we find similar spatial regional distributions of TAWSS in both normal and stenotic arteries.

Conclusions: Our data suggest that 3D-QCA based TAWSS is feasible in both normal and stenotic arteries. Spatial TAWSS distributions between the two methods are similar with agreement in matched TAWSS comparisons, though there are some small systematic differences in the absolute values of TAWSS, due to different resultant arterial geometries. These encouraging data suggest that further clinical evaluation of rapid TAWSS from 3D-QCA is warranted, which may facilitate clinical adoption of TAWSS assessment.

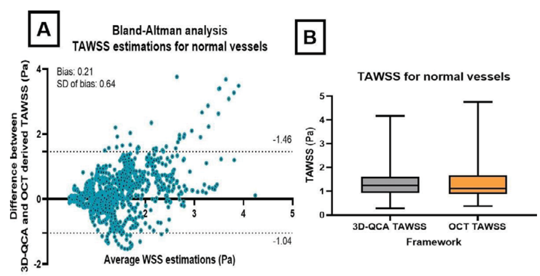

Figure 1. TAWSS estimations between 3D-QCA and OCT-CFD for normal vessels. ***A) Blant-altman analysis for all normal vessels; B) comparison of TAWSS ranges for both methods (n=15 Wilcoxon matched-pairs signed ranked tests)***

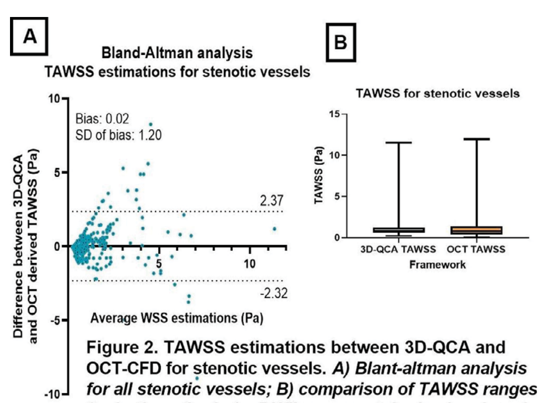

Figure 2. TAWSS estimations between 3D-QCA and OCT-CFD for stenotic vessels. ***A) Blant-altman analysis for all stenotic vessels; B) comparison of TAWSS ranges for both methods (n=5 Wilcoxon matched-pairs signed ranked tests)***