INTRODUCTION
Turbulent blood flow is often the result of some sort of pathology condition, e.g. the unstable flow developed downstream an aortic coarctation. The energy associated with these types of stenotic flows, the turbulent kinetic energy (TKE), will feed on the energy of the main flow, the kinetic energy (KE), and as a result increase the heart work load in order to maintain peripheral blood flow.

The advantages using TKE is that it can be measured with MRI and also proven to have a good relation versus simulated data, using computational fluid dynamics (CFD). Thus, a combined framework can therefore not only predictable using simulations but can also be validated post-intervention by MRI.

In the present study TKE triggered in the region of an coarctation was estimated for both pre-intervention and a variety of post-intervention configurations using scale-resolved image-based CFD. In addition, the correlation between TKE and pressure drop over a control volume was investigated.

RESULTS

Figure 1: Left: Maximum intensity projection with imposed geometry, Right: patient-specific aortic coarctation model (left) with three different simulated dilatations at 11%, 17% and 45% area increase.

The geometry and flow data was acquired using 3D level set segmentation and 2D PC-MRI respectively. The intervention procedure was mimicked using an inflation simulation. A scale-resolving turbulence model, LES, was utilized to resolve the significant turbulent scales. All cases were simulated using baseline cardiac output (CO) and with a 20% CO increase from baseline due to possible flow adaption.

Figure 2: Showing the results for pre-intervention (baseline) versus one possible post-intervention outcome (case 5). Left: Indicating a significant reduction of the volume integral of TKE due to the geometrical change, even at 20% higher cardiac output. Middle and right: Isovolume of the TKE and normal to the centerline planes projected with the KE at peak systole respectively. Notice how the baseline KE of the jet hits the wall causing additional TKE. This effect is reduced post-intervention where the jet is more centered, despite the flow adaption.

Figure 3: Left: Normalized time integral of the volume integral of TKE (representing the total TKE during the cardiac cycle) versus the normalize smallest stenotic area (normal to the centerline). Results shows a clear non-linear decay of TKE for enough area increase. Note however that too small dilatation in combination with enough flow adaption (i.e. case 1 and 2) the total TKE could end up above baseline, which is not desirable. Right: Normalized total TKE versus the normalized maximal pressure drop in systole. Results indicates a almost linear relationship between TKE and the pressure drop.

CONCLUSION
This non-invasive framework have shown the geometrical impact on the TKE estimates. The good correlation between pressure drop and TKE show the possibilities of estimating the former indirectly through MRI. TKE estimates using CFD combined with MRI measurement could have great potential for future intervention planning and follow-up studies.