In this study, a comparison between velocity fields for a plane wave 2-D vector flow imaging (VFI) method and a computational fluid dynamics (CFD) simulation is made. VFI estimates are obtained from the scan of a flow phantom, which mimics the complex flow conditions in the carotid artery. Furthermore, the precision of the VFI method is investigated under laminar and complex flow conditions in vivo. The carotid bifurcation of a healthy volunteer was scanned using both fast plane wave ultrasound and magnetic resonance imaging (MRI). The acquired MRI geometry of the bifurcation was used for fabricating an anthropomorphic flow phantom, which was also ultrasound scanned. The same geometry was used in a CFD simulation to calculate the velocity field. Results showed that similar flow patterns and vortices were estimated using CFD and VFI in the phantom. Velocity magnitudes were estimated with a mean difference within 15%, however, it was 23% in the external branch. For the in vivo scan, the precision in terms of mean standard deviation (SD) of estimates aligned to the cardiac cycle was highest in the center of the common carotid artery (SD 4.7° for angles) and lowest in the external branch and close to the vessel wall (SD 15.0° for angles).