

Comparison of 2D and 3D calculation of left ventricular torsion as circumferential-longitudinal shear angle using MRI tagging

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Background: Left ventricular (LV) torsion can be described as the circumferential-longitudinal (CL) shear angle. This method allows for torsion to be comparable between patients since it incorporates LV size. Furthermore it is most related to the fiber orientations in the myocardial wall. The CL shear angle can be calculated from 2D¹ or 3D² datasets, where the 3D approach is closest to the true shear angle, but the 2D approach is much faster. This study compares both methods in a set of healthy volunteers, to indicate whether it is legitimate to calculate LV torsion from a 2D dataset only.

Methods: In six male healthy volunteers, cine imaging with complementary myocardial tagging (CSPAMM) was acquired on a 1.5T Siemens Magnetom Sonata whole body system, with a steady state free precession (SSFP) sequence and a multiple brief expiration breath hold scheme³. Prospective triggering was used with a temporal resolution of 14 ms. The field of view (FOV) was 300x300mm², the excitation flip angle 20°, repetition time (TR) = 4.7 ms, echo time (TE) = 2.3 ms, receiver bandwidth (BW) = 369 Hz/pixel, imaging matrix size = 256x78. Five short axis (SA) slices, evenly distributed over the LV, as seen on an end-systolic 4-chamber image, were acquired with both horizontal and vertical tagging. For the 3D analysis, three additional long axis (LA) planes uniformly distributed around the LV and perpendicular to the SA with the tagging direction parallel to the SA slices were acquired. Tag line distance was equal to 7 mm. Myocardial trajectories were tracked in all slices using the extended HARP method⁴. The 2D approach to calculate the CL shear angle is described by the following equation [1]:

$$T = \frac{(\phi_{\text{apex}} - \phi_{\text{base}}) \cdot (\rho_{\text{apex}} + \rho_{\text{base}})}{2 \cdot D}$$

where T is the shear angle, Φ the rotation of the myocardium around its center, ρ the radius of the ventricle and D the distance between the basal and apical slice. In the 3D approach, displacements were interpolated between the LA planes and combined with the trajectories on the SA planes. A mesh of tetrahedrons was defined using the tracked points in intersecting regions of contours of neighbouring image planes. The 3D Lagrangian strain tensor was computed with the knowledge of the displacements of the points, from which the CL shear angle (α) could be computed [2]:

$$\varepsilon_i = \sqrt{1 + 2E_{ii}} - 1; \quad \sin \alpha_{ij} = \frac{2E_{ij}}{(\varepsilon_i + 1)(\varepsilon_j + 1)} \quad (i \neq j)$$

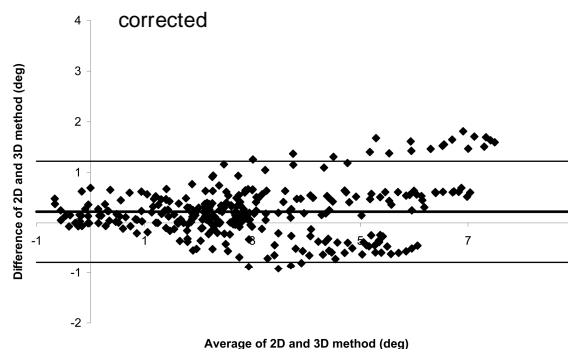
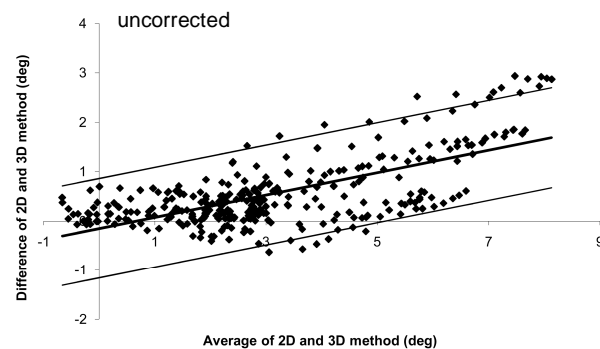
where E_{ii} are diagonal elements and E_{ij} are off-diagonal elements of the strain tensor, ε is the axial strain and i and j are indices of the circumferential and longitudinal direction. The results were averaged over the 5 slices to obtain a measure equivalent to that obtained with the 2D analysis.

For comparison of the methods, cross-correlations between the curves obtained with both methods were performed, as well as Bland-Altman analysis (for all subjects and time frames).

Results: The average maximum cross-correlation over all subjects between the 2D and the 3D methods was high ($r^2=0.99\pm0.01$) and the time delay between the curves was negligible. The torsion values obtained with the 2D analysis method were significantly higher than those obtained with the 3D analysis method. Bland-Altman analysis revealed a significant positive linear relationship between the difference in torsion and the average torsion ($r=0.67$, $p<0.0001$), the limits of agreement are therefore calculated as a regression line ($y = 0.23 \cdot x - 0.15 \pm 1.01^\circ$).

The linear relationship between the difference and the average shear angle computed with the 2D and 3D analysis method was further explored. Since the 2D method does not take the longitudinal shortening (LS) of the ventricle into account, it was hypothesized that this might explain the linear relationship between the difference and the average of both analysis methods. Therefore, the correlation between the difference between both methods and the average LS curve (also derived from Eq. [2]) was calculated. The average value of the LS, expressed as a fraction, was -0.08 ± 0.06 . The correlation coefficient for the difference between both methods and the LS was $r=0.51$, $p<0.0001$.

In addition, the 2D method was corrected for the LS by dividing the results from the 2D method by $(1-LS)$. When uncorrected, the distance between the basal and apical slices remains constant in the 2D method (Equation [1]), which underestimates the true distance between myocardial trajectories that are tracked with respect to the undeformed state. The correction therefore should increase the slice distance



a relationship between the difference and the average of the torsion values from both methods. Limits of agreement: $0.22\pm1.00^\circ$.

Conclusion: LV torsion represented as CL shear quantified by the 2D and 3D analysis methods are strongly related. Differences in torsion are predictable and might be explained by the longitudinal shortening of the LV. Therefore, it is legitimate to use the faster 2D method for torsion calculation.

References: 1. *Journal of Cardiovascular Magnetic Resonance* **10**, 26(2008), 2. *Magn Res Med* **57**, 485-493(2007), 3. *Magn Res Med* **49**, 722-730(2003), 4. *J Magn Res Im* **23**, 682-690(2006).