Left ventricular torsion obtained using equilibrated warping in patients with repaired Tetralogy of Fallot

Daniel Alexander Castellanos MD [1], Kateřina Škardová MS [2], Abhijit Bhattaru [3], Gerald Greil MD PhD [1,4], Animesh Tandon MD [1,4], Jeanne Dillenbeck MD [4], Barbara Burkhardt MD [5], Tarique Hussain MD PhD [1,4], Martin Genet PhD [6,7], Radomir Chabiniok MD PhD [1,2,6,7,8]

1 Division of Pediatric Cardiology, Department of Pediatrics, University of Texas Southwestern Medical Center, Dallas, TX, USA., 2 Department of Mathematics, Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Prague, CZ, 3 The College of New Jersey, Ewing, NJ, USA, 4 Division of Pediatric Radiology, Department of Radiology, University of Texas Southwestern Medical Center, Dallas, TX, USA., 5 Pediatric Heart Center, University Children's Hospital Zürich, Zürich, CH., 6 Solid Mechanics Laboratory (LMS), École Polytechnique/CNRS/ Institut Polytechnique de Paris, France, 7 Inria, France, 8 School of Biomedical Engineering & Imaging Sciences (BMEIS), St Thomas' Hospital, King's College London, United Kingdom

Background

- Patients with surgically repaired Tetralogy of Fallot (rTOF) exhibit poor left ventricular mechanics, which can lead to loss in left ventricular (LV) function.
- Early detection of loss in LV function are in demand for this clinical population.
- Torsion, also known as twist, is the difference in maximal rotation between LV base and apex at peak systole normalized to ventricular size (often reported by peak systolic twist gradient)
- Tissue tracking analysis of torsion using standard clinical software demonstrated poor reliability
- This study leverages a novel method of image registration to determine torsion in rTOF patients

Methods

- Seventy-six rTOF patients and ten healthy controls were included. Ventricular contours from routine clinical work were used.
- Standard tissue tracking software (cvi42, version 5.10.1, Calgary, Canada) was used to determine torsion in healthy controls.
- rTOF torsion calculation was based on the finite element method for image registration, and the equilibrium gap principle for problem regularization **(Fig. 1)**. The technique resamples DICOM images to determine peak systolic twist in volume meshes normalized to mesh length.
- rTOF patients in which torsion was successfully obtained were dichotomized into normal torsion and loss of torsion groups then compared by Mann-Whitney U and independent sample t-tests.
- Representative examples of normal torsion **(Fig. 2)** and loss of torsion **(Fig. 3)** are shown.

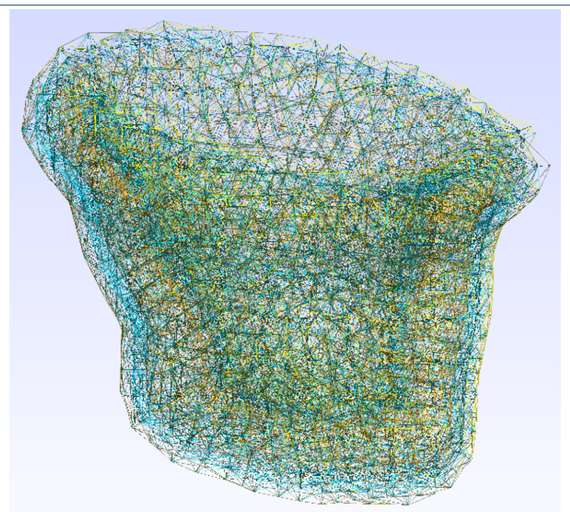

Figure 1: Example mesh of left ventricle provided. Clinical contours were used to create 3D triangulation of the ventricle.

Results

- Torsion by equilibrated warping was successfully obtained in 68 of 76 (89%) patients with repaired TOF and 9 of 10 (90%) normal controls.

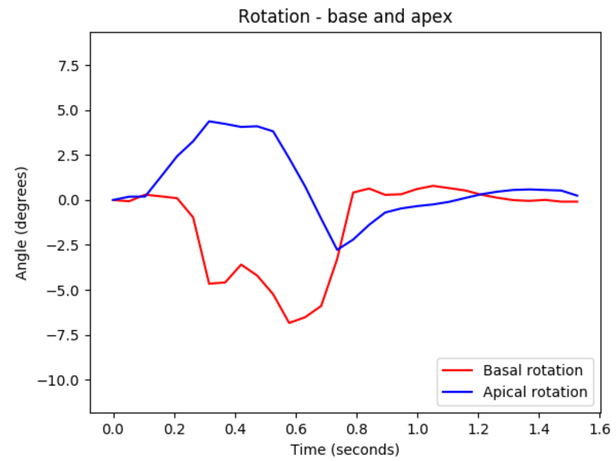

Figure 2: Normal torsion in a patient with repaired Tetralogy of Fallot. The x-axis represents time (seconds) during the cardiac cycle and the y-axis represents torsion (degrees). During systole, the base undergoes clockwise rotation (negative y-axis values) while the apex undergoes counterclockwise rotation (positive y-axis values). Peak systolic torsion is 9.16 degrees and occurs at 0.32 seconds. When normalized to mesh length, the peak systolic torsion gradient is 0.12 degrees/cm.

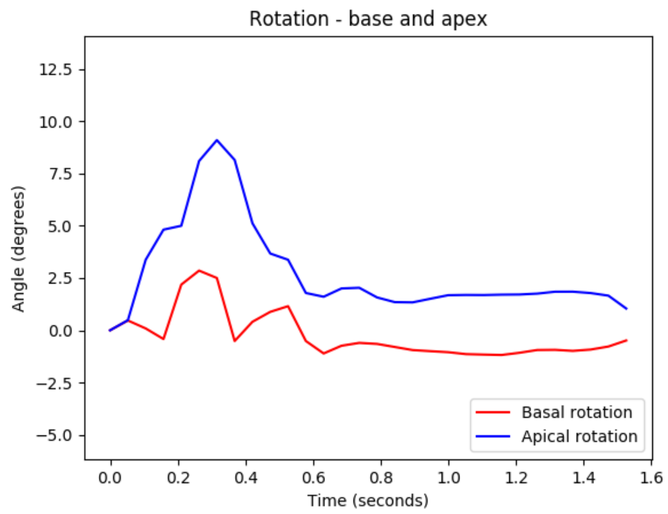

Figure 3: Reversal of normal basal systolic rotation in a patient with repaired Tetralogy of Fallot. During systole, both the base and apex undergo counterclockwise rotation. Peak systolic torsion is 8.65 degrees and occurs at 0.36 seconds. When normalized to mesh length, the peak systolic torsion gradient is 0.10 degrees/cm.

Results (cont.)

- The intra- and inter-observer coefficients of variation were 0.095 and 0.117, respectively; compared to 0.668 and 0.418 for tissue tracking by standard clinical software. The intra- and inter-observer intraclass correlation coefficients for equilibrated warping were 0.862 and 0.831, respectively; compared to 0.250 and 0.621 for tissue tracking.

Variable	Normal torsion (n=36)	Abnormal torsion (n=32)	P-value
Patients with shunt prior to initial repair	5 (13.9%)	4 (12.5%)	1.000
Age at MRI (years)	16.2 (1.9-39.6)	11.7 (3.4, 52.1)	0.012
Time from pulmonary valve intervention to MRI (years)	13.2 (0.7-37.6)	9.9 (2.9-49.6)	0.353
Peak systolic torsion (degrees)	10.19 (3.82-23.60)	6.42 (1.71-17.19)	<0.001
Peak systolic torsion gradient (degrees/cm)	0.16 (0.06-0.35)	0.01 (-0.08-0.28)	<0.001
RVEDVi (ml/m^2)	135 +/- 36	134 +/- 37	0.880
RVESVi (ml/m^2)	66 (37-121)	68 (27-125)	0.731
RVEF (%)	47.6 +/- 6.8	49.2 +/- 8.3	0.367
LVEDVi (ml/m^2)	75 +/- 12	78 +/- 15	0.485
LVESVi (ml/m^2)	32 +/- 8	34 +/- 10	0.540
LVEF (%)	57 (49-68)	57 (41-72)	0.892
RVEDV:LVEDV	1.8 +/- 0.4	1.8 +/- 0.5	0.712
Patients with Pulmonary valve intervention <1 year after MRI	13 (36.1%)	13 (40.6%)	0.804

Table 1: Characteristics of patients with repaired Tetralogy of Fallot with normal torsion and reversal of basal clockwise rotation. Reversal of basal clockwise rotation is labeled abnormal torsion. RV= right ventricle, LV= left ventricle, ESVi= end-systolic volume indexed to body surface area, EDVi= indexed end-diastolic volume, EF= ejection fraction.

Discussion

- The equilibrated warping method of image registration can be used in patients with repaired Tetralogy of Fallot with a 90% success rate.
- There was no significant association between loss of torsion and other ventricular parameters indicative of a worsening cardiac condition. Longitudinal follow-up is needed.

Conclusion

The equilibrated warping method of image registration to assess LV torsion shows good reliability in normal controls and is feasible in patients with rTOF.