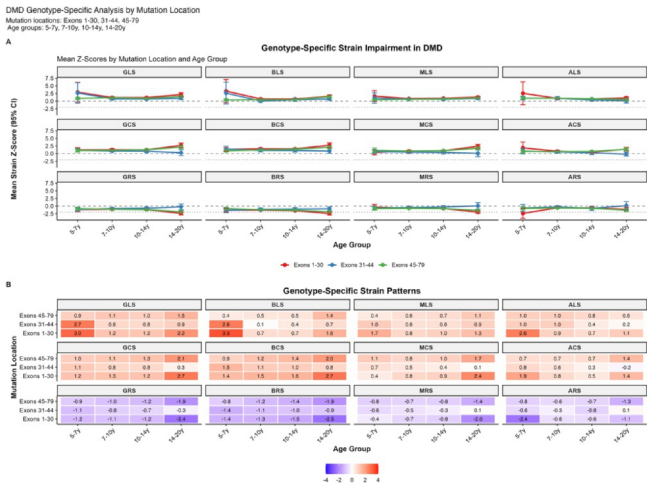

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Exaggerated Blood Pressure Response During Exercise Is Associated with Pathological Remodelling in Veteran Athletes

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Background: Endurance athletes often develop physiological left ventricular hypertrophy (LVH). However, certain athletes, particularly those who are older, may develop pathological remodelling in association with hypertension which can be particularly exacerbated during exercise.

Cardiovascular magnetic resonance (CMR) can distinguish between LVH due to increased myocyte mass and expansion of the extracellular compartment which may indicate pathological remodelling.

We aimed to assess the relationship of physical fitness and exercise blood pressure (BP) with the myocardial composition of veteran endurance athletes.

Methods: We prospectively recruited athletes (cyclists/triathletes) aged ≥ 40y who exercised for ≥ 6h/week for ≥ 10y. Exclusion criteria consisted of any pre-existing cardiovascular disease including arterial hypertension.

Participants underwent cardio-pulmonary exercise testing and CMR including cine imaging, native and post contrast T1 mapping (MOLLI) and late gadolinium enhancement (LGE). VO_2max was standardised by using % achieved predicted VO_2max (VO_2max/ VO_2max age-sex-weight predicted VO_2max). Extracellular volume (ECV) was calculated using standard methods and left ventricular mass indexed to body surface area (LVMI) calculated. From these, the myocardium was divided into intracellular mass (ICM) as 1-ECV x LVMI and extracellular mass (ECM) as ECV x LVMI.

Results: Two hundred and eight athletes were recruited (mean age 58.8 ± 7.3 years; 86.5% male). % achieved predicted VO_2max was 137.8 ± 18.5% and mean exercise systolic BP (SBP) was 211.6 ± 30.4mmHg (Table 1). 42.2 % of athletes had fibrosis, all in a non-ischaemic pattern.

On univariable linear regression, % achieved predicted VO_2max was significantly associated with LVMI (beta 0.15, P < 0.001) due to an increase in ICM (beta 0.15, P < 0.001) but not ECM (beta 0.0002, P = 0.83) (Table 2).

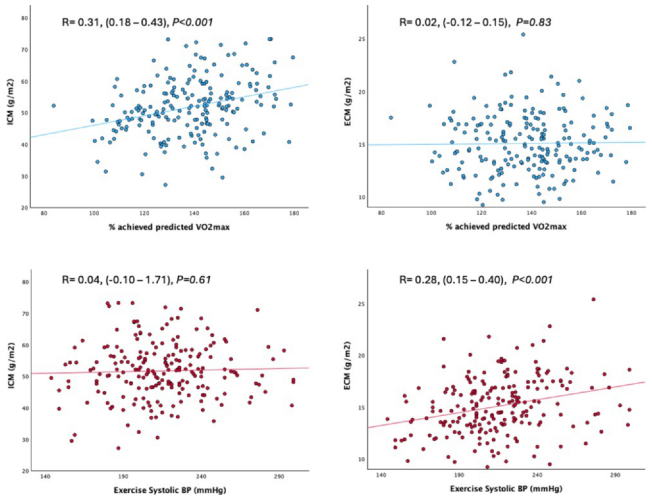
Exercise systolic BP was not associated with LVMI (beta 0.04, P = 0.15) with no association with ICM (beta 0.01, P = 0.61) but was significantly associated with ECM (beta 0.03, P < 0.001).

On logistic regression, the presence of non-ischaemic fibrosis was not associated with % achieved predicted VO_2max (odds ratio (OR) 1.00, P = 0.78) or exercise SBP (OR 1.00, P = 0.60) but was associated with increasing age (OR 1.08, P < 0.001).

Conclusion: In veteran athletes, increased physical fitness is associated with increased LV mass mediated via greater myocyte mass with no change in ECM - in keeping with physiological hypertrophy. However, greater systolic BP response to exercise is associated with an increase in ECM without affecting myocyte mass and overall LV mass. Therefore, increased extracellular mass may be a novel biomarker to distinguish physiological from pathological remodelling in veteran athletes with exercise-induced hypertension.

	n = 208
Baseline Characteristics	
Age (years)	58.8 ± 7.3
Male (n)	180 (86.5%)
BMI (kg/m^2)	24.2 ± 2.6
Resting HR (BPM)	53.1 ± 7.4
Systolic BP (mmHg)	118.8 ± 12.0
Diastolic BP (mmHg)	73.2 ± 7.4
Exercise History	
Training Hours per Week	10.9 ± 3.3
Active Years	30.7 ± 15.2
Cardio-pulmonary Exercise Test	
Maximum Heart Rate (BPM)	160.5 ± 15.0
Relative Power (W/kg)	4.3 ± 0.96
% achieved predicted VO_2max	137.8 ± 18.5
Exercise Systolic BP (mmHg)	211.6 ± 30.4
Exercise Diastolic BP (mmHg)	95.1 ± 18.0*
Cardiovascular Magnetic Resonance	
LVEDVi (ml/m2)	107.0 ± 15.3
LVEF (%)	57.3 ± 4.8
LVMi (g/m^2)	66.8 ± 10.8
RVEDVi (ml/m2)	110.7 ± 18.0
RVEF (%)	53.2 ± 5.8
LAVi (ml/m2)	45.9 ± 12.7
Native T1 (ms)	1249 ± 40
ECV (%)	22.1 ± 2.5
ICM (g/m^2)	51.7 ± 8.9
ECM (g/m^2)	15.1 ± 2.7
Fibrosis (%)	119 (42.2%)
Fibrosis mass when present (g)	2.35 ± 1.98
T2 (ms)	41.1 ± 2.2

	ICM (beta, 95% CI)	P Value	ECM (beta, 95% CI)	P Value
BMI (kg/m^2)	0.56 (-0.09 – 0.24)	**0.02***	-0.05 (-0.20 – 0.10)	0.49
Resting HR (BPM)	-0.36 (-0.52 – -0.20)	< **0.001***	-0.12 (-0.17 – -0.07)	< **0.001***
Systolic BP (mmHg)	0.20 (0.10 – 0.30)	< **0.001***	0.03 (0.00 – 0.06)	**0.049***
Diastolic BP (mmHg)	0.23 (0.07 – 0.40)	**0.006***	-0.01 (-0.06 – 0.05)	0.86
Active Years	0.16 (0.08 – 0.24)	< **0.001***	0.02 (-0.01 – 0.04)	0.15
% achieved predicted VO_2max	0.15 (0.09 – 0.21)	< **0.001***	0.002 (-0.02 – 0.02)	0.83
Exercise SBP (mmHg)	0.01 (-0.03 – 0.05)	0.61	0.03 (0.01 – 0.04)	< **0.001***
Exercise DBP (mmHg)	-0.04 (-0.11 – 0.03)	0.28	0.01 (-0.01 – 0.03)	0.50



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4D flow MRI using retrospective valve tracking for assessing atrioventricular valve regurgitantion in Fontan patients

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Background: Atrioventricular valve regurgitation (AVVR) is a major determinant of adverse outcomes in patients with single-ventricle physiology after Fontan surgery. Accurate quantification of AVVR is therefore critical in this population. In the general population, retrospective valve tracking with 4D flow MRI is the most commonly applied technique for evaluating mitral regurgitation. However, its validity in patients with single-ventricle physiology following Fontan surgery remains uncertain. We aimed to evaluate the accuracy of this method in this unique cohort.

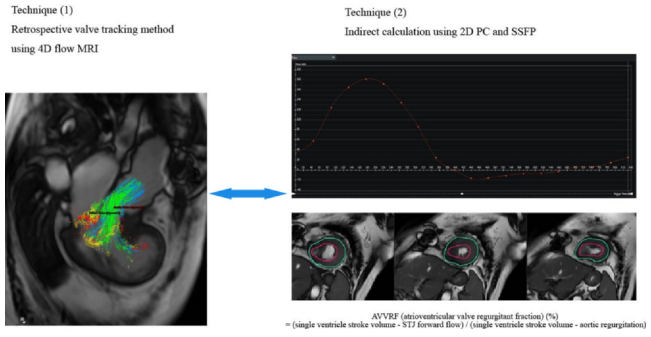
Methods: Nine patients with single-ventricle physiology after Fontan operation underwent cardiac magnetic resonance (CMR), including 4D flow MRI, at our center between March 2024 and July 2025. Examinations were performed on a 1.5T GE Artist scanner, and image post-processing was conducted using cvi42 (version 6.2.2; Circle Cardiovascular Imaging). AVVR was quantified using two approaches: (1) the retrospective valve tracking method, and (2) a conventional indirect 2D phase-contrast (PC) method, calculated as single-ventricle stroke volume from SSFP imaging minus sinotubular junction (STJ) forward flow, divided by single-ventricle forward stroke volume minus aortic regurgitation (Figure 1). Agreement between the two methods was evaluated using Pearson correlation analysis.

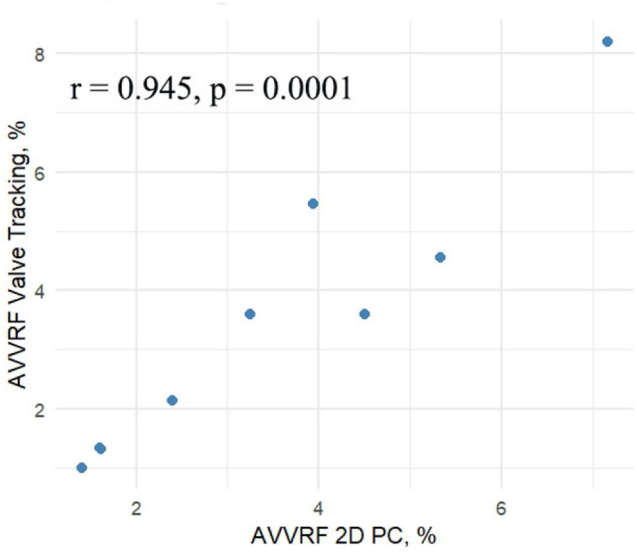
Results: Tricuspid atresia was the most common underlying diagnosis. Seven patients had undergone extracardiac conduit (ECC) Fontan, while two had atriopulmonary connection (APC) Fontan surgery. Both quantification methods demonstrated mild AVVR, with mean regurgitant fractions of 3.46% using the valve tracking method and 3.47% using the indirect 2D PC method. As shown in Figure 2, a strong correlation was observed between the two techniques (r = 0.945, p = 0.0001).

Conclusion: Retrospective valve tracking with 4D flow MRI provides a reliable approach for quantifying AVVR in patients with single-ventricle physiology after Fontan surgery.

Patient	Age	Sex	Diagnosis	Type of Fontan surgery
1	45	Male	Transposition of the great arteries with hypoplastic left ventricle	APC
2	43	Female	Tricuspid atresia	ECC
3	34	Male	Double inlet right ventricle	ECC
4	23	Male	Tricuspid atresia	ECC
5	31	Female	Tricuspid atresia	ECC
6	23	Female	Tricuspid atresia	ECC
7	43	Male	Double inlet left ventricle	ECC
8	25	Male	Criss-cross heart with double outlet right ventricle	ECC
9	35	Male	Tricuspid atresia	APC

ECC denotes extracardiac conduit; APC atriopulmonary connection.





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