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Features of the right atrium in repaired dextro-transposition of the great arteries following atrial switch operations (Insights from the CSONGRAD Registry and MAGYAR-Path Study)

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A R T I C L E I N F O

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A B S T R A C T

Background: In dextro-transposition of the great arteries (dTGA), the aorta and the pulmonary artery are transposed. The present study aimed a three-dimensional speckle-tracking echocardiography-derived determination of volumetric and functional features of the atrium being on the morphologic right side ['right atrium (RA)] in adult patients with dTGA.
Methods: The present study comprised 18 adult dTGA patients, four of whom were excluded due to inferior image quality. From the remaining 14 patients (mean age: 29.7 ± 8.1 years, 9 males), 7 cases underwent Mustard-procedure, while another 7 subjects underwent Senning-procedure. Their results were compared to that of 28 age- and gender-matched healthy subjects (28.8 ± 1.4 years, 20 males).
Results: Increased RA volumes respecting the cardiac cycle could be demonstrated in dTGA patients compared to controls. RA stroke volumes (SVs) for reservoir and conduit function were reduced together with impaired RA emptying fractions (EFs) featuring all phases of RA function. Mustard-operated patients showed tendentiously lower RA volumes and increased SVs and EFs respecting the cardiac cycle compared to those of Senning-operated patients suggesting beneficial results for Mustard-procedure. Reduced RA global and mean segmental peak RA strains and RA strains at atrial contraction could be detected in dTGA patients compared to those of controls with tendentiously lower values in Mustard-operated patients compared to those of Senning-operated subjects.
Conclusions: Significant RA volumetric and functional abnormalities could be detected in adult dTGA patients following atrial switch repair. While RA volumetric data proved to be better in Mustard-operated patients, RA strains were enhanced in Senning-operated subjects.

1. Introduction

In dextro-transposition of the great arteries (dTGA), the aorta and the pulmonary artery are transposed, which means that the aorta originates from a morphological right ventricle (RV), while the pulmonary artery originates from a morphological left ventricle (LV) [1–4]. dTGA is a rare, potentially life-threatening cyanotic heart defect due to non-communicating adjacent systemic and pulmonary circuits incompatible with life [1–4]. Several surgical procedures were historically used in the clinical practice to shunt blood flow into the right direction including atrial switch operations like Senning- and Mustard-procedures [3,5] (see Fig. 1).

Atria show complex volumetric changes respecting the cardiac cycle with special contractility features [6–8]. Three-dimensional (3D) speckle-tracking echocardiography (3DSTE) is considered to be one of the most powerful imaging technique having ability of simultaneous detailed assessment of volumes and function of both atria at the same time using the same digitally created 3D virtual atrial model [9–11]. The present study aimed to determine 3DSTE-derived volumetric and functional features of the atrium being on the morphologic right side ['right atrium (RA)] in adult patients with dTGA who underwent Senning- or Mustard-procedures.

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[1] This author takes responsibility for all aspects of the reliability and freedom from bias of the data presented and their discussed interpretation.

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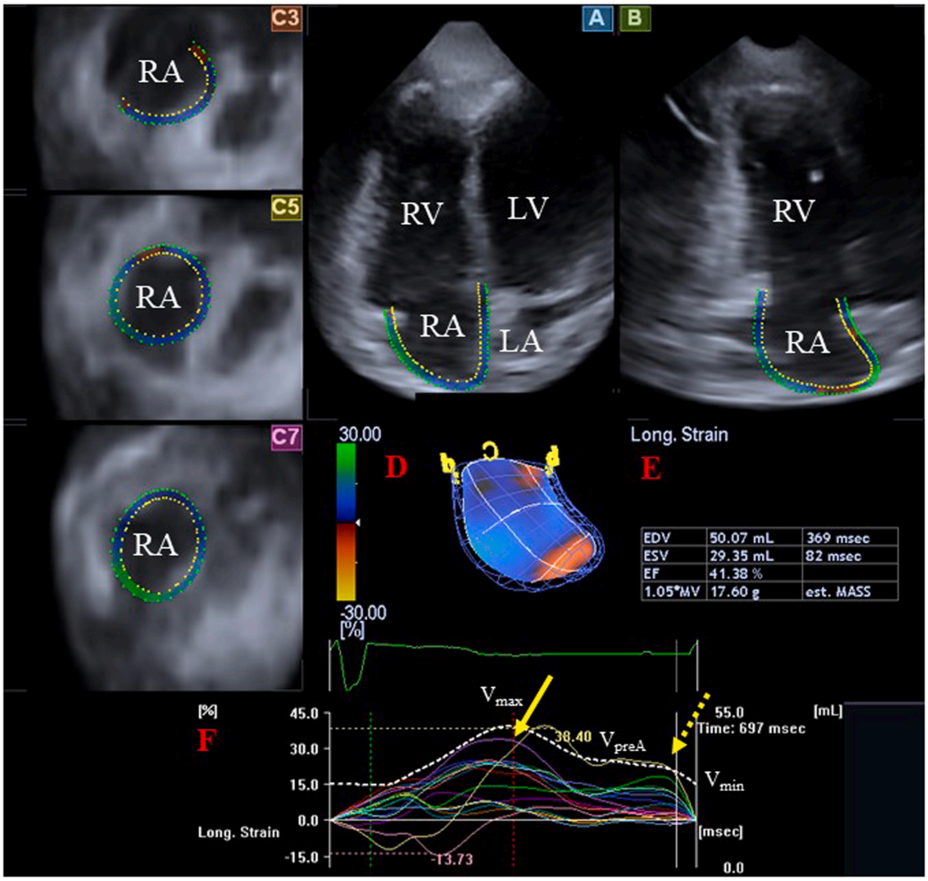

Fig. 1. Three-dimensional (3D) speckle-tracking echocardiographic right atrial (RA) assessment using a full-volume dataset in a patient with dextro-transposition of the great arteries is demonstrated: (A) apical four-chamber view, (B) apical two-chamber view, (C3) short-axis view at basal, (C5) mid- and (C7) superior RA level. The 3D RA cast (D) and RA volumetric data (E) are also presented. Coloured curves represent time – RA segmental (longitudinal) strains, while dashed white curve represents RA volume changes during the cardiac cycle with maximum (V_{max}), minimum (V_{min}) RA volumes and RA volume before atrial contraction (V_{preA}) (F). Peak RA strain is represented by a yellow arrow, RA strain at atrial contraction is represented by a dashed yellow arrow (F). **Abbreviations:** LA = left atrium, LV = left ventricle, RA = right atrium, RV = right ventricle. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2. Methods

2.1. Patient population

The present study comprised 18 adult dTGA patients, four of whom were excluded due to inferior image quality. The mean age of the remaining 14 patients was 29.7 ± 8.1 years and nine were male. Seven patients underwent Mustard procedure at the age of 2.0 ± 0.8 years, while another seven patients underwent Senning procedure at the age of 0.7 ± 0.5 years. Their medical history originates from the Registry of **C (S)ONG**enital cardiac **D**isease patients at the University of Szeged (**CSONGRAD Registry**), which summarizes clinical data of more than 4000 patients with CHD since 1961. A special study was organized at our department to analyse clinical usefulness of 3DSTE-derived parameters in certain disorders including dTGA [**M**otion **A**nalysis of the heart and **G**reat vessels b**Y** three-dimension**A**l speckle-t**R**acking echocardiography in **Path**ological cases (**MAGYAR-Path) Study**]. For comparisons, clinical data of 28 age- and gender-matched healthy subjects (28.8 ± 1.4 years, 20 males) were used. Subjects were considered to be healthy in the absence of any disorder or pathologic state and drug use and if echocardiographic and electrocardiographic (ECG) findings proved to be normal. All dTGA patients and controls were in sinus rhythm and underwent complete two-dimensional (2D) Doppler echocardiography and 3DSTE. Institutional human research committee of the University of Szeged has approved the study (project identification code: 71/2011). Informed consent was obtained from all subjects involved. The study complied with the 1975 Declaration of Helsinki.

2.2. Two-dimensional Doppler echocardiography

Commercially available cardiac ultrasound device Toshiba Artida™ (Toshiba Medical Systems, Tokyo, Japan) attached to a PST-30SBP phased-array transducer was used for evaluation of the LV and left atrial dimensions according to the available guidelines [12]. Mitral (MR) and tricuspid (TR) regurgitations were visually assessed using a 4 scale-grade. Valvular stenosis and LV diastolic function were quantified by Doppler echocardiography.

2.3. Three-dimensional speckle-tracking echocardiography

3DSTE was performed according to recent practices detailed earlier [9–11]. Firstly, data acquisition was made using the same Toshiba Artida™ (Toshiba Medical Systems, Tokyo, Japan) echocardiographic system, while transducer was changed to a 1–4 MHz PST-25SX matrix phased-array transducer (Toshiba Medical Systems, Tokyo, Japan). Using this transducer with ECG-gating and breath-holding, 6 wedge-shaped subvolumes were acquired from the apical window on the chest, from which full volume 3D datasets were created by the software. Secondly, chamber quantification was performed using the 3D Wall Motion Tracking software version 2.7 (Toshiba Medical Systems, Tokyo, Japan). Datasets were automatically analyzed in apical two- (AP2CH) and four-chamber (AP4CH) views and short-axis views positioned at basal, midatrial and superior RA levels. Following image optimizations, tricuspid annular edges (TA) and the endocardial side of the superior RA region were defined and then endocardial RA surface was automatically reconstructed creating a virtual 3D RA cast (Fig. 1).

2.4. 3DSTE-derived RA volumetric assessments

The following volumetric RA parameters were calculated [8]:

- V_{max}: end-systolic RA volume (largest LA volume before tricuspid valve opening),

Table 1
Demographic, clinical data and two-dimensional echocardiographic parameters in patients with dextro-transposition of the great arteries and controls.

	dTGA patients (n = 14)	Controls (n = 28)	p-value
Risk factors			
Age (years)	29.7 ± 8.1	28.8 ± 1.4	0.5
Male gender (%)	9 (64)	20 (71)	0.7
Hypertension (%)	4 (29)	0 (0)	0.01
Hypercholesterolemia (%)	0 (0)	0 (0)	1
Diabetes mellitus (%)	0 (0)	0 (0)	1
Two-dimensional echocardiography			
LA diameter (mm)	35.2 ± 6.4	38.1 ± 4.1	0.2
LV end-diastolic diameter (mm)	46.4 ± 4.6	46.9 ± 3.3	0.8
LV end-diastolic volume (ml)	107.7 ± 16.1	96.4 ± 23.4	0.3
LV end-systolic diameter (mm)	29.7 ± 4.2	31.2 ± 2.9	0.3
LV end-systolic volume (ml)	37.8 ± 10.9	35.9 ± 8.1	0.6
Interventricular septum (mm)	10.5 ± 2.6	8.9 ± 1.3	0.02
LV posterior wall (mm)	9.7 ± 1.7	9.3 ± 1.8	0.6
LV ejection fraction (%)	63.7 ± 6.2	64.2 ± 3.2	0.8

Abbreviations: dTGA: dextro-transposition of the great arteries, LA: left atrium; LV: left ventricle.

- V_{preA}: early diastolic RA volume (detected on ECG before atrial contraction at time of P wave)
- V_{min}: late diastolic RA volume (smallest RA volume before tricuspid valve closure)

Using RA volumes, RA stroke volumes (SVs) and emptying fractions (EFs) were calculated:

Systolic reservoir function:

- TASV – total atrial stroke volume ($=V_{max} - V_{min}$)
- TAEF – total atrial emptying fraction ($=TASV/V_{max} \times 100$).

Early diastolic conduit function:

- PASV – passive atrial stroke volume ($=V_{max}–V_{preA}$)
- PAEF – passive atrial emptying fraction ($=PASV/V_{max} \times 100$).

Late diastolic active contraction (booster pump function):

- AASV – active atrial stroke volume ($=V_{preA} - V_{min}$).
- AAEF – active atrial emptying fraction ($=AASV/V_{preA} \times 100$).

2.5. 3DSTE-derived RA strain assessments

Strains are quantitative features of wall contractility. Several global (featuring the whole RA), segmental (featuring only one RA segment), mean segmental (featuring RA as a mean of all segments) and regional (featuring basal, midatrial and superior RA regions from segmental values) strains were calculated [7]. Due to the fact that all segments have special 3D movement and contractility, **u**nidimensional/unidirectional radial (RS) (featuring thickening and thinning of the RA segment), longitudinal (LS) (lengthening and shortening of the RA segment), circumferential (CS) (widening and narrowing of the RA segment), multidimensional/multidirectional/complex area (AS) (combination of LS-CS) and 3D (3DS) RA strains (combination of LS-CS-RS) were calculated, as well. RA strain curves have two peaks, the first one characterizes the RA reservoir phase (peak strain), while the second one features its booster pumping function (RA strain at atrial contraction). Due to the absence of a specific RA segmentation model, the segmentation model of the LV was used during measurements.

Table 2
Comparison of three-dimensional speckle-tracking echocardiography-derived volumetric right atrial parameters of patients with dextro-transposition of the great arteries and controls.

	Controls (n = 28)	dTGA patients (n = 14)	Senning-operated dTGA patients (n = 7)	Mustard-operated dTGA patients (n = 7)
Calculated Volumes (ml)				
V_{max}	51.9 ± 16.3	73.5 ± 58.1	73.1 ± 54.4	73.9 ± 65.9
V_{min}	29.1 ± 10.7	55.9 ± 45.6*	58.0 ± 49.0	53.7 ± 45.8*
V_{preA}	38.1 ± 13.4	65.7 ± 50.3	71.3 ± 54.6	61.0 ± 50.1
Stroke Volumes (ml)				
TASV	22.8 ± 9.1	17.7 ± 15.1*	15.1 ± 6.8*	20.2 ± 20.8
PASV	13.8 ± 7.9	10.4 ± 11.8*	7.4 ± 3.2*	13.0 ± 16.0
AASV	9.0 ± 5.6	8.2 ± 5.0	9.3 ± 4.2	7.2 ± 5.7
Emptying fractions (%)				
TAEF	43.8 ± 11.5	25.0 ± 10.6*	24.9 ± 11.0*	25.2 ± 11.1*
PAEF	26.2 ± 12.4	13.3 ± 6.6*	11.6 ± 5.1*	14.7 ± 7.7*
AAEF	23.5 ± 11.5	14.7 ± 8.8*	17.1 ± 9.9	12.6 ± 8.0*

* – $p < 0.05$ vs Controls.
Abbreviations: dTGA: dextro-transposition of the great arteries, V_{max}: maximum right atrial volume; V_{min}: minimum right atrial volume; V_{preA}: right atrial volume before atrial contraction; TASV: total atrial stroke volume; TAEF: total atrial emptying fraction; AASV: active atrial stroke volume; AAEF: active atrial emptying fraction; PASV: passive atrial stroke volume; PAEF: passive atrial emptying fraction.

2.6. Statistical analysis

While continuous variables are presented as mean values ± standard deviation (SD), categorical variables are presented as frequencies and percentages. Student *t* test, $\chi 2$ test and Fisher's exact test were used for comparisons when appropriate. P value<0.05 was considered to be statistically significant. Software package Medcalc was used during statistical analysis (MedCalc, Mariakerke, Belgium).

3. Results

3.1. Demographic and 2D echocardiographic data

Demographic and 2D echocardiographic data are presented in Table 1. Among the risk factors, only the presence of hypertension, from 2D echocardiographic data, only the thickness of the interventricular septum differed significantly between operated dTGA patients and controls. dTGA was associated with atrial and ventricular septal defect and patent ductus arteriosus in 2, 4 and 5 patients, respectively. Grade 1–2 mitral regurgitation (MR) was present in 2 patients, while grade 2–4 MR did not occur. Grade 1–2 and 3–4 TR was present in 7 and 4 dTGA patients, respectively. None of the healthy controls showed MR or TR. None of dTGA and healthy controls had significant valvular stenosis on any valves. The mean age at the first procedures was 1.4 ± 1.0 years in the dTGA group of patients. The mean period between the procedure and the 3DSTE proved to be 29.5 ± 8.0 years.

3.2. 3DSTE-derived RA volumetric data

Increased RA volumes with large SDs respecting the cardiac cycle could be demonstrated in dTGA patients compared to controls. RA-SVs for reservoir and conduit function were reduced together with impaired EFs featuring all phases of RA function. Mustard-operated patients showed tendentiously lower RA volumes and increased SVs

Table 3
Comparison of three-dimensional speckle-tracking echocardiography-derived global and mean segmental peak right atrial strain parameters in patients with repaired transposition of the great arteries and controls.

	Controls (n = 28)	TGA patients (n = 14)	Senning-operated dTGA patients (n = 7)	Mustard-operated dTGApatients (n = 7)
Global strains				
Radial (%)	−17.2 ± 9.7	−8.0 ± 7.2*	−10.0 ± 7.6	−6.0 ± 6.7*
Circumferential (%)	21.2 ± 15.4	7.7 ± 4.9*	8.8 ± 5.6*	6.5 ± 4.2*
Longitudinal (%)	35.3 ± 12.8	14.4 ± 10.2*	15.9 ± 11.3*	12.8 ± 9.7*
3D (%)	−6.7 ± 6.2	−4.8 ± 5.0	−6.1 ± 5.5	−3.6 ± 4.4
Area (%)	66.5 ± 44.4	22.2 ± 14.1*	25.1 ± 15.0*	19.4 ± 13.7*
Mean segmental strains				
Radial (%)	−22.3 ± 8.4	−13.9 ± 6.7*	−14.7 ± 7.6 *	−13.0 ± 6.1*
Circumferential (%)	27.9 ± 14.7	12.0 ± 5.1*	13.9 ± 5.4*	10.1 ± 4.4*
Longitudinal (%)	40.2 ± 12.2	16.7 ± 10.1*	18.2 ± 11.3*	15.3 ± 9.3*
3D (%)	−13.2 ± 6.6	−10.0 ± 4.8	−10.7 ± 5.5	−9.3 ± 4.2
Area (%)	77.6 ± 45.0	27.8 ± 14.6*	31.2 ± 15.7*	24.4 ± 13.7*

* – $p < 0.05$ vs Controls.
Abbreviations: dTGA: dextro-transposition of the great arteries, 3D: three-dimensional.

Table 4
Comparison of three-dimensional speckle-tracking echocardiography-derived regional peak right atrial strain parameters in patients with repaired transposition of the great arteries and controls.

	Controls (n = 28)	dTGA patients (n = 14)	Senning-operated dTGA patients (n = 7)	Mustard-operated dTGA patients (n = 7)
RS $_{basal}$ (%)	−16.3 ± 7.5	−12.3 ± 7.9	−11.6 ± 10.6	−13.0 ± 4.6
RS $_{midatrial}$ (%)	−22.7 ± 10.1	−12.1 ± 6.3*	−12.9 ± 6.3*	−11.3 ± 6.6*
RS $_{superior}$ (%)	−30.8 ± 13.3	−18.8 ± 12.9*	−22.0 ± 11.8	−15.5 ± 14.0*
CS $_{basal}$ %)	27.9 ± 11.6	9.6 ± 6.4*	11.5 ± 7.3*	7.8 ± 5.3*
CS $_{midatrial}$ (%)	23.5 ± 12.0	10.5 ± 5.0*	11.9 ± 4.7*	9.0 ± 5.1*
CS $_{superior}$ (%)	34.2 ± 34.6	17.9 ± 11.1*	20.6 ± 12.6	15.3 ± 9.5
LS $_{basal}$ (%)	43.6 ± 19.1	16.7 ± 13.3*	18.7 ± 16.5*	14.6 ± 10.1*
LS $_{midatrial}$ %)	45.7 ± 15.4	21.6 ± 12.5*	22.7 ± 11.5*	20.5 ± 14.3*
LS $_{superior}$ (%)	27.0 ± 23.0	9.6 ± 5.5*	10.8 ± 6.5*	8.4 ± 4.4*
3DS $_{basal}$ (%)	−8.6 ± 5.6	−9.4 ± 6.3	−9.1 ± 8.7	−9.8 ± 3.4
3DS $_{midatrial}$ (%)	−11.9 ± 7.0	−7.7 ± 3.6*	−8.4 ± 4.0	−7.1 ± 3.4*
3DS $_{superior}$ %)	−22.1 ± 11.6	−14.3 ± 9.9*	−16.6 ± 8.6	−12.0 ± 11.1
AS $_{basal}$ (%)	70.8 ± 38.9	22.7 ± 17.3*	26.1 ± 19.3*	19.2 ± 15.8*
AS $_{midatrial}$ (%)	78.2 ± 33.6	31.6 ± 18.0*	34.2 ± 15.3*	29.1 ± 21.2*
AS $_{superior}$ (%)	86.9 ± 109.1	29.7 ± 20.2*	34.2 ± 23.0	25.1 ± 17.4

* – $p < 0.05$ vs Controls.
Abbreviations: dTGA: dextro-transposition of the great arteries, RS: radial strain; CS: circumferential strain; LS: longitudinal strain; 3DS: three-dimensional strain; AS: area strain.

Table 5
Comparison of three-dimensional speckle-tracking echocardiography-derived global and segmental right atrial strain parameters at atrial contraction in patients with repaired transposition of the great arteries and controls.

	Controls (n = 28)	dTGA patients (n = 14)	Senning-operated dTGA patients (n = 7)	Mustard-operated dTGA patients (n = 7)
Global strains				
Radial (%)	−6.9 ± 6.6	−4.4 ± 7.1	−5.4 ± 8.1	−3.4 ± 6.5
Circumferential (%)	12.1 ± 11.1	4.8 ± 4.2*	6.1 ± 5.0	3.5 ± 3.1*
Longitudinal (%)	8.9 ± 10.0	4.1 ± 3.7	6.3 ± 3.9	2.0 ± 2.1*, †
3D (%)	−3.3 ± 5.3	−1.7 ± 5.3	−2.6 ± 5.6	−0.8 ± 5.3
Area (%)	25.3 ± 31.0	10.3 ± 11.4	13.5 ± 14.4	7.2 ± 7.1
Mean segmental strains				
Radial (%)	−9.1 ± 5.5	−6.2 ± 4.9	−6.3 ± 4.8	−6.2 ± 5.3
Circumferential (%)	13.5 ± 9.5	6.2 ± 4.7*	7.5 ± 5.3	5.0 ± 4.0*
Longitudinal (%)	11.4 ± 5.4	7.1 ± 4.1*	9.5 ± 4.1	4.6 ± 2.3*, †
3D (%)	−5.6 ± 4.9	−4.3 ± 4.3	−4.8 ± 4.2	−3.7 ± 4.8
Area (%)	27.7 ± 22.2	14.5 ± 11.1*	17.8 ± 13.6	11.2 ± 7.4*

* – $p < 0.05$ vs Controls.
† – $p < 0.05$ vs Senning group.
Abbreviations: dTGA: dextro-transposition of the great arteries, 3D: three-dimensional.

and EFs respecting the cardiac cycle (except in active contraction) compared to those of Senning-operated patients suggesting beneficial results in case of the Mustard-procedure (Table 2).

3.3. 3DSTE-derived RA peak strains

Reduced RA global and mean segmental peak strains could be detected in dTGA patients compared to those of controls with tendentiously lower values in Mustard-operated patients compared to those of Senning-operated subjects (Table 3). Regional peak LA strains of dTGA patients and controls are presented in Table 4.

3.4. 3DSTE-derived RA strains at atrial contraction

Similarly, impaired global and mean segmental RA strains at atrial contraction were present in dTGA patients as compared to those of controls (Table 5). Most RA strains at atrial contraction were lower in Mustard-operated patients compared to those of Senning-operated subjects. Regional RA strains at atrial contraction in dTGA patients and controls are presented in Table 6.

4. Discussion

dTGA is a complex congenital heart defect originating from an embryological discordance between the aorta and the pulmonary trunk leading to the development of a parallel circulation with systemic and

Table 6
Comparison of three-dimensional speckle-tracking echocardiography-derived regional right atrial strain parameters at atrial contraction in patients with repaired transposition of the great arteries and controls.

	Controls (n = 28)	dTGA patients (n = 14)	Senning-operated dTGA patients (n = 7)	Mustard-operated dTGA patients (n = 8)
RS $_{basal}$ **(%)**	−6.7 ± 5.6	−4.4 ± 5.0	−2.3 ± 4.5*	−6.4 ± 4.9
RS $_{midatrial}$ **(%)**	−9.7 ± 6.7	−6.4 ± 6.4	−6.6 ± 6.4	−6.2 ± 7.0
RS $_{superior}$ **(%)**	−11.9 ± 8.4	−8.7 ± 8.5	−11.8 ± 8.9	−5.6 ± 7.5
CS $_{basal}$ **%)**	11.7 ± 8.3	3.5 ± 4.9*	4.6 ± 5.0*	2.4 ± 4.9*
CS $_{midatrial}$ **(%)**	10.5 ± 7.5	5.4 ± 4.4	7.2 ± 3.7	3.7 ± 4.6*
CS $_{superior}$ **(%)**	18.5 ± 23.9	11.5 ± 9.1	12.3 ± 11.3	10.7 ± 7.2
LS $_{basal}$ **(%)**	10.8 ± 5.1	6.3 ± 3.9*	8.9 ± 3.4	3.7 ± 2.2*, †
LS $_{midatrial}$ **%)**	11.9 ± 6.3	8.6 ± 5.4	12.0 ± 5.0	5.2 ± 3.3*, †
LS $_{superior}$ **(%)**	11.7 ± 13.1	5.9 ± 4.6	6.7 ± 6.0	5.0 ± 3.0
3DS $_{basal}$ **(%)**	−3.4 ± 5.5	−3.3 ± 5.2	−2.8 ± 6.3	−3.7 ± 4.2
3DS $_{midatrial}$ **(%)**	−5.0 ± 5.5	−3.4 ± 4.3	−3.6 ± 3.8	−3.1 ± 5.0
3DS $_{superior}$ **%)**	−9.7 ± 7.0	−7.1 ± 7.4	−9.6 ± 6.6	−4.7 ± 7.9
AS $_{basal}$ **(%)**	22.8 ± 14.8	9.9 ± 9.2*	12.3 ± 9.5*	6.9 ± 8.5*
AS $_{midatrial}$ **(%)**	24.0 ± 13.1	15.9 ± 13.1	20.4 ± 15.4	10.8 ± 8.9*
AS $_{superior}$ **(%)**	40.6 ± 63.0	19.4 ± 16.8	22.2 ± 21.4	15.6 ± 11.0

* – $p < 0.05$ vs Controls.
† – $p < 0.05$ vs Senning group.
Abbreviations: dTGA: dextro-transposition of the great arteries, RS: radial strain; CS: circumferential strain; LS: longitudinal strain; 3DS: three-dimensional strain; AS: area strain.

pulmonary flows not connected to each other with 90% mortality in the first year if left untreated [1,2]. Until the 1990s, atrial switch operations represented a physiologic palliation for dTGA leaving the RV the systemic ventricle and the LV the pulmonary ventricle, later the more anatomic arterial switch operation become prevalent [1]. In case of both Senning- and Mustard procedures, venous baffle pathways are created in order to redirect systemic venous blood to the LV and pulmonary venous blood to the RV. While autologous native tissue is used during the Senning-procedure, synthetic material is used for the Mustard-procedure [1–4]. Since early 1990s, the arterial switch operation had become the standard state-of-the-art procedure with excellent early outcomes, when the aorta and pulmonary artery are switched back to their normal positions [13].

Atria have a complex function serving as a reservoir is systole, a conduit in early diastole and a booster pump in late diastole [6,14]. Due to the special morphology in dTGA following atrial switch repair, RA is filling from the pulmonary veins and blood flow leaves to the systemic, but morphological RV [1,4].

3DSTE offers complete option for the evaluation of both atria including volumetric and strain assessment respecting the cardiac cycle using the same virtually created 3D atrial cast [6]. Cyclic changes in atrial volumes, stroke volumes and emptying fractions and strains could be investigated by 3DSTE featuring all reservoir, conduit and booster pump phases of RA function [6–8]. In a recent review, different patterns of RA volumetric and functional abnormalities could be detected in certain disorders ranging from mild (hypereosinophilic syndrome) to severe (tetralogy of Fallot) alterations [15].

Significant LA abnormalities could be detected in dTGA in a recent study [16]. End-systolic (maximum) LA volume was reduced with preserved early (pre-atrial contraction) and late (minimum) diastolic LA volumes in dTGA patients. It was accompanied with reduced LA-SVs and LA-EFs in all phases of LA function in dTGA patients late after atrial switch operations. LA strains at the reservoir phase (peak) and at atrial contraction were significantly impaired, as well. Patients having undergone Senning-operation had lower LA volumes and higher LA-SVs, LA-EFs and LA strains suggesting better long-term results associated with this type of procedure.

To the best of the authors' knowledge, this is the first time for detailed evaluation of volumetric and contractility features of RA in adult dTGA patients following Senning- and Mustard-procedures. In contrast to LA, increased RA volumes could be detected in dTGA patients, but similarly to LA, RA-SVs, RA-EFs and RA strains were reduced compared to matched controls. Interestingly, while RA volumetric data proved to be better in Mustard-operated patients, RA strains were enhanced in Senning-operated subjects.

Although little is known about the prognostic impact of RA strains [17], LA strains are known to have prognostic role in the prediction of cardiovascular outcome in several clinical scenarios [18]. This could highlight our attention on RA strains, which could theoretically have similar impact on outcome in disorders, where the morphologic right heart is affected as in dTGA. Further studies are warranted to confirm present findings and for clarification of prognostic impact of 3DSTE-derived volumetric and functional RA features in adult dTGA patients.

Limitation section. The following limitations have arisen during evaluations:

- Image quality for 3DSTE is lower than that of 2D echocardiography, which could affect the results significantly [9–11].
- 3DSTE-derived volumetric, strain and rotational parameters of other cardiac chambers were not examined.
- The present study did not aim to validate 3DSTE-derived atrial volumetric and strain measurements due to its validated nature [9].
- Although atrial switch operation was widely used, only a few dTGA patients could be recruited for this follow-up [1–4].
- Most dTGA patients had hypertension, which could affect the results. However, controls were age- and gender-matched.
- The shape and localization of the baffle could also affect the results.
- Strains of not contracting regions (like synthetic material) were 0 during measurements. This could partially explain low strain values of Mustard-operated dTGA patients.
- LV segmentation model was used during assessments due to the absence of a specific 3DSTE-derived RA segmentation model.

5. Conclusions

Significant RA volumetric and functional RA abnormalities could be detected in adult dTGA patients following atrial switch operation. While RA volumetric data proved to be better in Mustard-operated patients, RA strains were enhanced in Senning-operated subjects.

CRediT authorship contribution statement

Attila Nemes: Conceptualization, Writing – original draft, Writing – review & editing. **Árpád Kormányos:** Methodology, Software, Investigation, Data curation, Writing – review & editing. **Nóra Ambrus:** .

Kálmán Havasi: Resources.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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