

# Follow up after atrial switch surgery in patients with transposition of the great arteries; reality versus guidelines

Williams, Jake; Stoll, Victoria; Arif, S.; Bowater, S.; Thorne, S.; Clift, Paul; Hudsmith, Lucy

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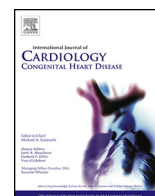
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## International Journal of Cardiology Congenital Heart Disease

journal homepage: [www.journals.elsevier.com/international-journal-of-cardiology-congenital-heart-disease](http://www.journals.elsevier.com/international-journal-of-cardiology-congenital-heart-disease)Follow up after atrial switch surgery in patients with transposition of the great arteries; reality versus guidelines<sup>☆</sup>J. Williams<sup>a,b,\*</sup>, V.M. Stoll<sup>a,c</sup>, S. Arif<sup>a</sup>, S. Bowater<sup>a</sup>, S. Thorne<sup>a,d</sup>, Paul F. Clift<sup>a,c</sup>, L.E. Hudsmith<sup>a</sup><sup>a</sup> Department of Adult Congenital Cardiology, Queen Elizabeth Hospital Birmingham, Birmingham, UK<sup>b</sup> Sheffield Teaching Hospitals, Sheffield, UK<sup>c</sup> Institute of Cardiovascular Sciences, University of Birmingham, Birmingham, UK<sup>d</sup> Department of Adult Congenital Cardiology, Toronto, Canada

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## ABSTRACT

**Introduction:** Atrial switch surgery, previously the intervention of choice for transposition of the great arteries, has been superseded by the arterial switch operation. The cohorts of patients who received atrial switch operations remain at risk of complications including sudden cardiac death, heart failure, and arrhythmias and require life-long monitoring. The American Heart Association issued guidance in 2018 about how follow up should be undertaken. We sought to compare the follow up regime suggested by these, and the European Society of Cardiology guidelines to the reality of that achieved in a specialist ACHD centre.

**Methods:** Patients under follow up after atrial switch surgery at a Level 1 centre were identified; demographic and clinical data were collected. Timeframes of follow up were compared to those suggested by the guidelines.

**Results:** We identified 110 patients following atrial switch surgery. At the end of the study period 94 patients (median age 41, IQR 11), remained under follow up. There were 16 patients whom had either died or undergone transplantation. Over two-thirds (65,69%) received a specialist clinic review within the recommended timeframe. Almost one fifth, 17 patients (18%) underwent cardiac magnetic resonance imaging within the recommended timeframe.

**Conclusion:** Our results show that achieving the recommended timeframes for patient follow up following atrial switch surgery is challenging in real life clinical practice. Future studies are needed to provide evidence for optimal follow up intervals that result in improvements in patient outcomes, given the cost and resource implications of these enhanced follow up regimes.

## 1. Introduction

Transposition of the great arteries is characterised by atrioventricular concordance and ventriculoarterial discordance. It was first described in 1797 and conferred a dismal prognosis until the mid-twentieth century, when atrial switch surgical techniques were developed by Senning and Mustard to palliate this defect [1–3]. Concerns over the long term sequelae of these techniques led to atrial switch surgery being superseded by the arterial switch operation [4,5].

Atrial switch procedures confer a lifelong risk of complications. Systemic right ventricles are prone to dysfunction, ultimately resulting in heart failure, with this incidence increasing in each decade of life following the atrial switch procedure [6–8]. A meta-analysis by

Venkatesh et al. found approximately one-fifth of deaths in atrial switch patients were due to congestive cardiac failure [6]. Heavy atrial scarring sustained through the surgical construction of baffles predisposes these patients to arrhythmias, affecting 60% of patients 20 years after surgery [6,7]. Other significant sequelae are baffle leaks and baffle stenosis. Baffle leaks are commonly seen in the long-term follow up of these patients and are an important risk factor for paradoxical strokes [9]. Baffle obstruction can cause a variety of complications including superior vena cava syndrome, hepatic cirrhosis and pulmonary hypertension [7,9]. Pulmonary hypertension is a finding of concern in atrial switch patients, and although baffle stenoses are a cause of pathologically elevated pulmonary arterial pressures, the aetiology of pulmonary hypertension in the vast majority of these patients is not yet fully understood [7,10]. The

<sup>☆</sup> These authors take responsibility for all aspects of the reliability and freedom from bias of the data presented and their discussed interpretation.

\* Corresponding author. Royal Hallamshire Hospital, Sheffield, S10 2JF, UK.

E-mail address: [jake.williams5@nhs.net](mailto:jake.williams5@nhs.net) (J. Williams).

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turbulent flow in these structurally altered hearts means patients are at an increased risk of infective endocarditis [11]. Systemic atrioventricular valve regurgitation (morphological tricuspid valve) is known to occur in this group of patients, though it does not typically cause additional complications such as heart failure [6,12].

The most serious complication for patients following atrial switch surgery is that of sudden cardiac death (SCD). SCD is the commonest cause of late post-surgical mortality in these patients [6]. Furthermore, patients with atrial switch repairs for transposition of the great arteries have some of the highest rates of SCD amongst all patients with congenital heart disease [13]. The risk of SCD has been shown to be strongly predicted by the presence of supraventricular tachyarrhythmias [14]. Therefore identification of arrhythmic events in this cohort of patients during follow up is important.

In 2018 the American Heart Association (AHA) published guidance on the management of Adults with Congenital Heart Disease (ACHD). These guidelines stipulate the type and frequency of follow up for patients who have received atrial switch surgery [15]. The suggested aspects of follow up are outpatient ACHD specialist review, electrocardiogram, echocardiogram, pulse oximetry, Holter monitoring, cardiac magnetic resonance imaging and cardiopulmonary exercise testing. The frequency of follow up is varied according to a novel ACHD anatomical and physiological grading system. Transposition of the great arteries is classed as anatomical complexity grade III (the highest), and the physiological stage is classed from A to D depending on various subjective and objective clinical parameters, with the highest score determining a patient's physiological stage.

In 2020 the European Society of Cardiology (ESC) updated guidance on the management of patients with congenital heart disease, providing recommendations for the follow up of patients with Senning and Mustard repairs for transposition of the great arteries [16]. The ESC and AHA guidance differ in that the ESC guidance does not use a physiological staging system, nor a rigid timeline of follow up frequency. ESC guidance discusses the serious and frequently occurring complications in Senning and Mustard patients and advises clinicians on how best to approach and investigate these sequelae, with particular reference to the common pitfalls in standard cardiac imaging modalities in detecting subtle changes in atrial switch physiology. The clinical utility of quantitative exercise testing in assessing cardiac symptoms and function is emphasised, rather than relying on subjective reporting of exercise tolerance which may be falsely reassuring. The prognostic importance of late gadolinium enhancement on magnetic resonance imaging is also highlighted. Additionally the challenges of diagnosing pulmonary hypertension are addressed and a low threshold for cardiac catheterisation is suggested [15,16].

We sought to compare the 'real-world' follow up of our patients based at the level 1 ACHD Centre at University Hospitals Birmingham (UHB) against the specific regime recommended by the American Heart Association and European Society of Cardiology guidelines.

## 2. Methods

### 2.1. Patient cohort and data collection

Adult patients who had undergone either a Mustard or Senning procedure for transposition of the great arteries who were under follow up at the level 1 ACHD Centre, Queen Elizabeth Hospital, University Hospitals Birmingham were identified. This study was registered and approved by the hospital's Clinical Audits and Registries Management Service (CARMS) (reference 15080).

Patient information was collected from electronic patient records between March to October 2019. Patient demographic data was collected including age, gender, age at time of atrial switch surgery and current medications. Catheter ablation for arrhythmia and heart transplantation were noted if present. Other data were collected to allow comparison to the AHA guidelines, these included details of their last outpatient review,

electrocardiogram results, pulse oximetry readings, Holter monitor/device interrogation results, and cardiopulmonary exercise test results. Imaging reports from echocardiographic studies and magnetic resonance examinations were also recorded. Where multiple results were available for the same investigation, only the most recent result was documented. Mortality data and data regarding the presence or absence of complications such as baffle leaks, were collected to determine the outcomes of our patients compared to those suggested by the ESC guidelines.

### 2.2. Statistical methods

Data were collected and analysed using a data collection tool constructed on Microsoft Excel 2020 (Microsoft, Washington) and further analyses were conducted using SPSS 2020 (IBM, New York). The Shapiro-Wilk test of normality was utilised in SPSS to determine which data were parametric (presented in the text as mean  $\pm$  SD) and which data were non-parametric (presented as median (interquartile range)).

### 2.3. Echocardiography methods

Echocardiograms were undertaken using standard ultrasound equipment (Philips iE33 Medical Systems, The Netherlands). Right ventricular dilatation was noted and right ventricular function was graded by echocardiogram using a range of imaging parameters, including experienced operator visual assessment, fractional area change (<35% defined as abnormal) and tissue Doppler derived tricuspid lateral annular systolic velocity ( $S' < 10$  defined as abnormal), in accordance with American Society of Echocardiography guidelines [17]. Function was then graded as normal, mildly impaired, moderately impaired, and severely impaired according to these parameters.

### 2.4. Cardiac magnetic resonance imaging

Cardiac Magnetic Resonance (CMR) imaging was performed using a 1.5 T scanner (Magnetom Avanto, Siemens, Germany). Cardiac morphology and function were studied using standard CMR protocols, with steady state free precession cine images. Typical imaging parameters were temporal resolution 40–50 msec, repetition time 3.2 msec, echo time 1.7 msec, flip angle 60°, field of view 300 mm, spatial resolution  $1.5 \times 1.5 \text{ mm}^2$ , slice thickness 7 mm with 3 mm gap and minimum 25 phases per cardiac cycle in accordance with previously validated methodology [18]. Image analysis was performed off-line using cvi42 (Circle Vascular Imaging, Calgary, Canada). Ventricular volumes and function were calculated from standard contouring of the ventricular short axis stack in end diastole and end systole, as per Biobank protocols [18].

### 2.5. Comparison of follow up regime compared to guideline recommendations

AHA guidelines suggest that frequencies of each aspect of follow up are based upon each patient's physiological stage. Patients were classified into physiological stage (A to D) as per the AHA guidelines, and New York Heart Association functional class based on the demographic and clinical data collected from their patient records [15]. For each patient the time period between their most recent follow up and date of data collection was calculated for each aspect of their follow up regime. This time interval was then compared to those recommended by the AHA guidelines for their physiological stage to see whether the recommendations had been met. Comparison was also made with ESC Guidelines.

## 3. Results

### 3.1. Patient cohort demographics

One hundred and ten patients with previous Senning or Mustard operations who were, or had been under active follow up prior to death

or transplantation were identified. At the time of data collection, five patients had received a heart transplant. One of the patients who received a heart transplant died. Of the patients who did not receive a heart transplant, eleven had died.

Of those who died, 5 were in physiological Class C, and 6 in Class D. For those patients who underwent transplantation, 2 were Class C and 3 were Class D (including the one who died). Therefore 94 patients with a systemic right ventricle remained under follow up by the adult congenital heart team; adherence to timeframes suggested by AHA guidelines are presented for these 94 patients only. Of these 94 patients, 56 patients were male (60%). The median age of patients still alive at the time of data collection was 41 years (IQR: 11), ranging from 28 to 56 years old.

The majority of patients had undergone a previous Mustard procedure (59 patients, 63%) compared to a Senning procedure (35 patients, 37%). Fifty-four of these patients (57%) had the operation within the first year of life.

Results for NYHA class and AP physiological stage are given in Table 1. The majority of patients were in NYHA Class I (66 patients, 70%), whilst not one patient was Class IV. For the AP physiological stage classification, most patients were stage C (71 patients, 76%), followed by stage B (21 patients, 22%) and then stage D (2 patients, 2%). No patients were in Stage A. A Stage C classification was mainly due to either moderate or greater ventricular dysfunction, or arrhythmias controlled with treatment. Catheter ablation for arrhythmia had been performed in 27 patients (29%). The majority of patients (n = 60, 64%), were prescribed at least one cardiac medication. Of the patients prescribed medications, 43 patients (46%) were prescribed beta blockers, 32 patients (34%) angiotensin-converting enzyme (ACE) inhibitors, 35 patients (37%) were prescribed either warfarin or a direct oral anticoagulant, and 22 patients (23%) were prescribed a diuretic.

### 3.2. Outpatient clinic appointments

For the 94 patients alive and continuing with follow up, 65 (69%) had received a clinic review within the timeframe for their physiological stage as recommended by the AHA guidelines.

### 3.3. Electrocardiogram

Fifty six patients (60%) had an electrocardiogram recorded within the timeframe recommended for their physiological stage. For 90 patients an ECG at some point over the course of their follow up was available for rhythm interpretation, or a summary of the ECG rhythm was recorded in

**Table 1**  
Clinical status of atrial switch patients, electrocardiogram and pulse oximetry results.

	NYHA status (n = 94)
Class I, n (%)	66 (70)
Class II, n (%)	20 (21)
Class III, n (%)	8 (9)
Class IV, n (%)	0 (0)
	AP Physiological stage (n=94)
A, n (%)	0 (0)
B, n (%)	21 (22)
C, n (%)	71 (76)
D, n (%)	2 (2)
	ECG rhythm (n=90)
Sinus, n (%)	65 (72)
Paced, n (%)	19 (21)
Abnormal atrial focus, n (%)	6 (7)
	Pulse oximetry oxygen saturations (n=83)
>94%, n (%)	69 (83)
91–94%, n (%)	11 (13)
88–90%, n (%)	1 (1)
<87%, n (%)	2 (2)

NYHA stands for New York Heart Association; AP, anatomical/physiological; ECG, electrocardiogram.

a clinic letter, see Table 1. 65 patients (69%) were in sinus rhythm. The ECG for six patients demonstrated either atrial tachycardia or atrial flutter. Conduction abnormalities could be assessed for 83 patients, whilst cardiac axis could be assessed for 80 patients. A right bundle branch block pattern was present for 46 patients (49%) and a left bundle branch block in 2 patients (2%). Widespread T-wave inversion was present in the ECGs of 35 patients (37%). The majority of ECGs demonstrated right axis deviation (n = 64, 68%), followed by a normal axis (n = 11, 12%), whilst left axis deviation was found the least (n = 5, 5%). PR interval duration could be assessed for 80 patients, of these 15 patients (16%) had a PR interval greater than 200msec.

### 3.4. Transthoracic echocardiogram

Of the 94 patients with ongoing follow up, 54 (57%) had a transthoracic echocardiogram within the timeframe recommended by their physiological stage. A full echocardiography report was available for 87 patients. Sixty five (69%) patients were noted to have significantly dilated systemic right ventricles. Systemic ventricular function was most commonly mildly impaired (n = 41, 44%) and severely impaired in 12 patients (13%). The degree of tricuspid regurgitation most frequently seen was mild (n = 42, 45%), see Table 2. Three patients (3%) had a baffle leak noted on their most recent echocardiogram.

### 3.5. Pulse oximetry

Fifty eight patients (62%) had their pulse oximetry documented within the stipulated timeframe for their physiological stage. Results of pulse oximetry were available for 83 patients, the majority of patients (n = 69, 73%) had saturations above 94%, see Table 1.

### 3.6. Holter monitoring

Thirty three patients (35%) of the ninety four with ongoing follow up had a form of ambulatory electrocardiogram (ECG) recording within the

**Table 2**  
Echocardiographic and cardiac magnetic resonance imaging data [29].

Echocardiographic data (n = 87)		
	Grading	(n)
<b>Right ventricular function</b> (n=77)	Normal	12
	Mildly impaired	41
	Moderately impaired	12
	Severely impaired	12
<b>Tricuspid regurgitation</b> (n=87)	None/Trivial	15
	Mild	42
	Moderate	20
	Severe	6
	Tricuspid valve replacement	4
Cardiovascular Magnetic Resonance data (n=55)		
	Parameter	Median(IQR)/ Mean±SD
<b>Right ventricle (systemic)</b>	End diastolic volume (ml)	183 (84)
	End systolic volume (ml)	81 (57)
	Stroke volume (ml)	91 ± 26
	Ejection fraction (%)	52 ± 11
<b>Left ventricle (subpulmonary)</b>	End diastolic volume (ml)	116 ± 36
	End systolic volume (ml)	43 (24)
	Stroke volume (ml)	70 ± 21
	Ejection fraction (%)	62 ± 11

Data presented as mean±SD or median(IQR). SD, standard deviation; IQR, interquartile range.

recommended timeframe for their physiological stage. For eight of these patients the ambulatory recording was with a Holter monitor, the other 25 patients had a device *in situ* that could be interrogated for any rhythm disturbances. Six patients had an intra-cardiac defibrillator (ICD), five had a Reveal device and fourteen had a pacemaker.

Ambulatory ECG monitoring results conducted at any point in the past were available for 67 patients in total. 41 patients (44%) had a Holter monitor report. 5 patients had a Reveal device *in situ*. 21 patients had a permanent cardiac device *in situ* (6 ICD; 15 pacemakers) capable of detecting and recording rhythm abnormalities.

Four patients were noted to have a mean heart rate lower than 60 bpm, whilst eight patients had episodes of non-sustained ventricular tachycardia detected on their ambulatory ECG recording.

### 3.7. Cardiac magnetic resonance imaging

In our cohort of 94 patients, 21 (22%) had either an ICD or a permanent pacemaker *in situ*. These patients were deemed to have been ineligible for CMR due to the potential contraindication of their cardiac device. By excluding these 21 patients from the 94 under follow up, 73 patients could have undergone CMR. Seventeen of these 73 patients (23%) had a documented CMR study within the timeframe recommended for their physiological stage. Fifty-five patients of the 73 patients without a device (75%) had undergone at least one CMR study during their follow up. The volumetric results for these studies are summarised in Table 2. A baffle leak was identified on CMR in seven patients. Of the 21 patients that had either an ICD or a permanent pacemaker, 8 patients previously had a CMR study at some point in the past. This means that in our overall figure of 94 patients, 63 (67%) had undergone at least one CMR study during follow up.

In the 17 patients with a CMR study within the timeframe recommended by the AHA for their physiological stage, 10 patients (59%) also received an echocardiogram within the recommended timeframe, and 11 patients (65%) received an exercise test within the recommended timeframe.

Conversely, in the remaining 56 patients that did not receive a CMR within the timeframe recommended by the AHA for their physiological stage, 44 patients (79%) received an echocardiogram within the recommended timeframe, and 30 patients (54%) received an exercise test within the recommended timeframe. Eleven patients had undergone late gadolinium enhancement as part of a CMR examination. None of these had any visible areas of late gadolinium enhancement within their systemic right ventricle.

### 3.8. Exercise test

Forty one of the patients (44%) with ongoing follow up had undertaken an exercise test within the recommended timeframe for their physiological stage. For the majority of patients (39 patients), this was in the form of a cardiopulmonary exercise test, 2 patients undertook a shuttle test.

Results from an exercise test were available in 73 patients (78%). Of these, 71 had undertaken a standardised ramped protocol cardiopulmonary exercise test. The mean duration of exercise was 8 min 58 s with a standard deviation of 2 min 40 s. The median peak VO<sub>2</sub> was 22.6 ml/kg/min (IQR: 7.6 ml/kg/min). The mean VE/VCO<sub>2</sub> slope was 34 ± 6, range 22–48.

### 3.9. Overall adherence to guideline timeframes and relationship to physiological staging

Of the ninety four patients remaining under follow up, ten had undergone all seven follow up procedures within the timeframe recommended by the AHA guidelines for their physiological stage. Eighteen patients had undergone four aspects of the follow up regime, whilst another 16 had completed five aspects of the follow up regime. Of the

remaining patients, 14 had not had any part of their follow up regime within the recommended timeframe, whilst 6 had one aspect, 9 had two aspects, 9 had three aspects and the remaining 12 had completed six follow up procedures in the timeframe suggested by the AHA guidelines.

Each physiological stage subgroup (A-D) was examined for its individual adherence to AHA timeframe recommendations for follow-up. Full results for this can be seen in Table 3. As patients moved into progressively more ‘severe’ physiological stages, adherence to each aspect of follow-up increased. The exception was CMR, which was more commonly used in physiological stage ‘B’ patients than stage ‘C’.

## 4. Discussion

Our results show that achieving the recommended guideline timeframes for follow up of patients following atrial switch surgery is challenging in real life clinical practice. We found that the best adherence to the guidelines was for outpatient clinic review and the worst for cardiac magnetic resonance imaging frequency.

### 4.1. Adherence to guideline timeframes

#### 4.1.1. Outpatient clinic appointments

In our population of atrial switch patients, over two thirds had a completed outpatient specialist ACHD review within the recommended guideline timeframe for their physiological stage. Maintaining regular clinic reviews with a dedicated ACHD specialist team is a crucial aspect of the lifelong care these patients require. We noted that many patients did not attend appointments that had been scheduled and this was why follow up had failed to occur in a timely manner. These patients are likely to be affected by working lives and looking after young families. Additionally, it may be that if they feel well they may choose to extend the time between clinic appointments by rescheduling themselves [19].

#### 4.1.2. Cardiac investigations

The investigation that was least frequently conducted within the appropriate timeframe according to AHA guidelines was cardiac magnetic resonance (CMR) imaging. 21 patients had a cardiac device that posed a potential contraindication to CMR imaging. ESC guidance regarding care of patients with congenital heart disease states that ACHD patients with implanted cardiac devices should receive CMR investigations, provided the device is MR conditional and appropriate support is available [16,20]. However the diagnostic value of CMR studies in patients with devices may be significantly impaired by artefact [21,22]. Additionally CMR is not universally tolerated due to claustrophobia. Compared to other aspects of follow up recommended by AHA guidelines, CMR is the most expensive to perform and in a publicly funded health care system is usually utilised when there is a clinical change to suggest the need for a further study, rather than as routine surveillance at a fixed time point, especially if adequate imaging can be obtained with transthoracic echocardiography. Echocardiography was performed more frequently, according to the timeframes suggested by

**Table 3**  
Number and percentage of patients meeting follow-up criteria for each physiological stage.

	Physiological stage: N (%)			
	A (n = 0)	B (n = 21)	C (n = 71)	D (n = 2)
OP Clinic	–	9 (43)	54 (76)	2 (100)
ECG	–	7 (33)	47 (66)	2 (100)
TTE	–	11 (52)	41 (58)	2 (100)
Pulse oximetry	–	9 (43)	47 (66)	2 (100)
Holter	–	2 (9.5)	31 (44)	0 (0)
CMR	–	6 (29)	11 (15)	0 (0)
CPEX	–	8 (38)	32 (45)	1 (50)

OP: outpatient; ECG: electrocardiogram; TTE: transthoracic echocardiogram; CMR: cardiac magnetic resonance; CPEX: cardio-pulmonary exercise test.

the guidelines, than CMR supporting the role of echocardiography as more of a gatekeeper to CMR. In our patients that did not receive a CMR within their recommended timeframe, slightly more patients (79%) received an echocardiogram than those that did receive a CMR within their timeframe (59%), suggesting that possibly either an echocardiogram alone was seen as sufficient imaging during a follow up encounter, or that an additional echocardiogram was not deemed necessary following a CMR study.

AHA guidance for atrial switch patients states that where CMR is not available, Cardiovascular Computed Tomography (CCT) can be used in its place [15]. However, serial use of CCT constitutes a significant radiation exposure and increased future risk of malignancy in a relatively young patient population such as ours.

Performing more frequent CMR studies for our atrial switch patients is an area for improvement in our centre, as although there are health economic factors to consider in utilising costly investigations as mentioned above, the use of CMR can be of critical importance in a patient with complex congenital heart disease [23]. As ESC guidance recommends, CMR can be not only of diagnostic value for assessing complications following atrial switch surgery, but also an important step prior to interventional or electrophysiological procedures which are often required in these patients [16].

In the follow up of our atrial switch patients 44% had undergone a formal exercise test within the recommended AHA timeframe. Exercise testing forms a critical part of the follow up of atrial switch patients for several reasons. Firstly, there is strong evidence to correlate exercise test performance with prognosis in congenital heart disease patients [24]. Furthermore, it is recognised in patients with congenital heart disease that self-reported exercise tolerance poorly reflects true cardiovascular function, stemming from lifelong physical and psychological adaptations these patients make to their condition [25].

#### 4.2. Classification of patients according to physiological stage grading

Follow up procedure frequency is varied according to a novel anatomical/physiological grading system piloted by the 2018 American Heart Association guidelines [15]. As such this grading system is relatively new and not well validated for use in the long-term follow up of these complex patients, although in adults with various ACHD conditions it has been found to have better predictive power for early postoperative mortality than existing scoring systems [26]. The aim of this grading system was to capture the complexity of ACHD anatomy and physiology that are not always correlated. Although the data selected for inclusion in the anatomical/physiological grading system are known to confer importance for prognosis, management or quality of life, this data is across the whole spectrum of congenital conditions and not specific to any one group. Given the relatively small proportion of patients who have undergone atrial switch surgery compared to other congenital conditions the relevance of a grading system that is derived from data in other congenital conditions is uncertain. However the anatomical/physiological grading system is likely to be of greater relevance compared to grading systems that are derived from acquired heart disease data.

By including physiological variables as well as anatomical data the aim is that the grading system will be able to reflect the dynamic nature of managing patients with congenital heart disease that is not purely dependent on the description of their anatomy. This, as per the guideline would then result in an alteration in the frequency of monitoring, according to the patient's changing clinical circumstances. The ACHD grading system allows patients to move in either direction of severity depending upon their current clinical condition.

The majority of our patients were classed as physiological stage C due to either their ventricular dysfunction or treated arrhythmia. This mandates more frequent follow up procedures especially for Holter monitoring and magnetic resonance imaging than lower physiological classes. The use of physiological stages to define various aspects of follow-up mandates an assumption of a degree of uniformity in terms of clinical

status and prognosis within each physiological stage. However, given the complex nature of these atrial switch patients' conditions and the range of complications they experience, there likely exists significant variability within this group of patients sharing a physiological stage. Our data support this notion, as half of the patients who died were in Class C and not Class D, suggesting that further work is required to refine this grading system for use in determining the prognosis and risk of mortality in patients following atrial switch surgery.

Additionally we observed that as patients progressed through physiological stages follow up adherence increased, likely reflecting that as physiological parameters worsen and patients become more symptomatic, clinicians appropriately respond to these changes and investigate patients with increasing frequency accordingly.

#### 4.3. Evidence for guidelines

The level of evidence available to support the AHA guideline recommendations about follow up procedures/intervals following atrial switch surgery is limited. The evidence level for Holter monitoring and annual MRI or echocardiographic imaging is graded as expert opinion. The time intervals for all procedures have been based on expert opinion. There is no definitive evidence to suggest that outcomes are improved because of an increased frequency of monitoring in patients with a higher physiological stage. Therefore, for example, suggestions about whether exercise tests should be conducted every year versus every three years depending upon the physiological stage are arbitrary and not known to alter outcomes despite imposing a large additional service burden.

However it is increasingly recognised that congenital heart disease patients benefit from multi-modality imaging, which when used together, may detect subclinical complications. In patients with complex congenital heart disease it has been demonstrated that using other modalities of cardiovascular imaging (notably CMR) alongside echocardiography provides the most effective and appropriate diagnostic information in such complex patients and should be considered as standard care [27]. The additional cost of complementary imaging modalities may be offset by the avoidance of costly hospital admissions for heart failure management. Future multi-centre registry data and studies will be required to try and understand whether increased monitoring improves patient outcomes in order to further target clinical resources to the areas where they will have most benefit for patients.

#### 4.4. Recommendations from ESC guidelines and areas for improvement

The 2020 guidelines from the European Society of Cardiology are not prescriptive about timeframes regarding the follow up of atrial switch patients [16]. Rather, they highlight important areas of follow up including essential investigations and grant the clinician more autonomy on when to use these tests. To this end it can be said that the follow up of our atrial switch patients fulfilled the ESC guidelines more than the chronological criteria proposed by the AHA. Indeed, the highly experienced and specialist clinicians supervising the care of atrial switch patients will be aware of the fact that 'one size does not fit all' in such a complex patient population and that guidelines should be there to supplement and troubleshoot aspects of follow up rather than simply dictate frequency of investigations without a broader oversight to the clinical status of these patients.

In 2018 the European Heart Journal published guidance on cardiovascular imaging in congenital heart disease. This recommends a baseline CMR in the transition from paediatric to adult populations and proposes a 3-yearly interval between CMR studies for most ACHD patients with exceptions should clinical judgement suggest otherwise [27]. A proportion of our patients had never received a CMR, thus a baseline CMR was not achieved, and all patients in the atrial switch cohort have now reached adulthood. However, a 3-yearly interval between CMR studies proposes a "happy medium" of sorts between ESC guidelines, that do not suggest any specific timings for frequency of follow ups, and AHA

guidelines which could be seen as overly-rigorous for clinicians.

The predominant two areas identified in the follow up of our patients that demonstrated a need for improvement were the frequency of CMR studies and cardiopulmonary exercise tests. These have been widely described in the literature as crucial for atrial switch patients and we found that some patients in our cohort had not completed either one of these tests. Whilst there may be valid reasons for this which have not been recorded, it is important that all patients who have undergone atrial switch procedures receive these objective investigations alongside routine clinical review. Furthermore, the more extensive use of late gadolinium enhancement on CMR could improve our risk stratification for the risk of sudden cardiac death in our atrial switch patients as recognised in the literature [28].

#### 4.5. Limitations

This study is limited by the retrospective design and the absence of some data for a proportion of patients. Additionally we are unable to know if some patients have moved away from the area and are undertaking their follow up in a different hospital. The study was conducted at a single centre and therefore the applicability of these findings to other centres will need to be considered. This work assessed clinical care conducted in a country with publicly funded healthcare so the results may not be applicable to a healthcare system where reimbursement occurs for each clinical test and therefore more frequent tests may be favoured.

#### 5. Conclusions

In our large cohort of atrial switch patients we found that achieving the recommended AHA guideline timeframes for follow up was challenging in real life clinical practice. We found the follow up of our patient cohort was more suited to the less prescriptive guidance from ESC. The best adherence to the guidelines was for specialist outpatient review and the worst for cardiac magnetic resonance imaging frequency. This highlights some areas for improvement in our follow up. Future studies are required to support the use of the ACHD anatomical/physiological classification to determine frequency of follow up procedures and whether this has any effect on patient outcomes given the resource and cost implications of these enhanced follow up regimes. Expert ACHD clinician and multidisciplinary assessment is paramount for the long-term follow up of these complex patients as is patient education about the importance of life-long follow-up.

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#### Ethical standards

Ethical approval was not required for this study in accordance with the United Kingdom National Health Service National Research Ethics Service guidance because the study was undertaken by the direct clinical team using information previously collected in the course of routine care. This project was approved by the University Hospitals Birmingham NHS Foundation Trust.

#### Declaration of competing interest

None.

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None.

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