

openheart Impact of clinical follow-up and diagnostic testing on intervention for tetralogy of Fallot

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To cite: House AV, Danford DA, Spicer RL, *et al.* Impact of clinical follow-up and diagnostic testing on intervention for tetralogy of Fallot. *Open Heart* 2015;2:e000185. doi:10.1136/openhrt-2014-000185

Received 13 August 2014
Revised 3 February 2015
Accepted 4 March 2015

ABSTRACT

Objective: Our purpose was to evaluate yield of tools commonly advocated for surveillance of tetralogy of Fallot (TOF).

Methods: All patients (pts) with TOF, seen at any time from 1/2008 to 9/2013 in an academic cardiology practice were studied. At the first and each subsequent outpatient visit, the use of tools including history and physical (H&P), ECG, Holter (HOL), echocardiogram (Echo), MR or CT (MR-CT) and stress testing (STR) were noted. Recommendations for intervention (INT) and for time to next follow-up were recorded; rationale for each INT with attribution to one or more tools was identified.

Results: There were 213 pts (mean 11.5 years, 130 male) who had 916 visits, 123 of which (13.4%) were associated with 138 INTs (47 surgical, 54 catheter-mediated, 37 other medical). Recommended follow-up interval was 9.44±6.5 months, actual mean follow-up interval was 11.7 months. All 916 (100%) patient visits had a H&P which contributed to 47.2% of INT decisions. Echo was performed in 652 (71.2%) of visits, and contributed to 53.7% of INTs. MR-CT was obtained in 129 (14.1%) of visits, and contributed to 30.1% of INTs. ECG was applied in 137 (15%) visits, and contributed to 1.6% of INTs. HOL was obtained in 188 (20.5%) visits, and contributed to 11.3% of INTs. STR was performed at 101 (11%) of visits, and contributed to 8.9% of INTs.

Conclusions: INTs are common in repaired TOF, but when visits average every 11–12 months, most visits do not result in INT. H&P, Echo and HOL were the most frequently applied screens, and all frequently yielded relevant information to guide INT decisions. STR and MR/CT were applied as targeted testing and in this limited, non-screening role had high relevance for INT. There was low utilisation of ECG and major impact on INT was not demonstrated. Risk stratification in TOF may be possible, and could result in more efficient surveillance and targeted testing.

INTRODUCTION

Tetralogy of Fallot (TOF) is the most common cyanotic congenital heart defect (CHD).¹ Advances in surgical technique and postoperative care have dropped early surgical mortality in TOF to less than 2%, and well

KEY MESSAGES

What is already known about this subject?

- ▶ Appropriate tools must be selected for surveillance of patients with repaired tetralogy of Fallot so as to intervene when it is in their best interest. There is unsettled debate surrounding the ideal timing of pulmonary valve replacement and other interventions.

What does this study add?

- ▶ The study identified the relative yield of frequently and less frequently applied diagnostic modalities, and points to how the yield of these tools could possibly be enhanced by targeted testing and risk stratification.

How might this impact on clinical practice?

- ▶ Increasing numbers of adults with repaired tetralogy of Fallot are undergoing clinical surveillance. With an array of diagnostic tools available, and a counterbalancing concern over healthcare costs, optimising the frequency of clinical follow-up visits and the intensity of the testing performed at each is important.

over 85% of patients survive into adulthood.² Long-term outcomes and quality of life have also consistently improved for individuals with repaired TOF; however, several late complications are routinely observed. Chronic pulmonary regurgitation (PR)^{3–4} after TOF repair may result in right ventricular (RV) dilation and dysfunction, which in turn has been associated with exercise intolerance, arrhythmias and sudden death.^{5–6}

The Canadian Cardiovascular Society, the European Society of Cardiology and the American College of Cardiology have published guidelines for pulmonary valve replacement (PVR) in adults with repaired TOF,^{7–9} which are based on symptoms, severity of PR and degree of RV enlargement. However, given the lack of evidence from prospective studies proving that PVR decreases the risk of adverse events^{10–12} and the limited durability of PVR, the ideal timing of PVR remains an



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area of relative uncertainty, especially in asymptomatic patients. This has focused attention on the long-term follow-up of repaired TOF, with close surveillance of RV function forming a cornerstone of follow-up.

Uncertain as the cardiology community is regarding the ideal frequency and extent of outpatient surveillance, but armed with a wide variety of investigative tools at its disposal, there is potential for wide interinstitutional and intrainstitutional variability in outpatient surveillance practices. The purpose of this study was (1) to identify practice patterns for outpatient surveillance of repaired TOF in our institution over a period of 5 years, and (2) to evaluate the yield of investigational tools on outpatient visits with regard to decision-making for interventions (INTs) in this group of patients.

METHODS

This was a single-institutional, retrospective analysis of every outpatient follow-up visit for all patients with surgically repaired TOF seen at any time from 1/2008 to 9/2013 in an academic children's hospital-based paediatric-adult congenital cardiology group practice. The Institutional Review Board approved the study. We included TOF with pulmonary atresia, but excluded TOF with absent pulmonary valve, atrioventricular septal defect or other complex cardiac lesion.

At our institution, INT for severe PR in repaired TOF is undertaken for prevention of progressive RV dilation and dysfunction, tricuspid valve regurgitation, left ventricular dysfunction, tachyarrhythmias and diminished exercise tolerance. The potential for benefit from elimination of RV volume load is weighed against perceived surgical or transcatheter procedural risks on a case-by-case basis. Accordingly, before recommending PVR, clinical symptoms (such as exercise intolerance, other heart failure symptoms or syncope), imaging data, electrophysiological and haemodynamic factors are discussed in a multidisciplinary case conference. Volumetric and functional values which we believe warrant serious consideration for PVR include indexed RV end-diastolic volume greater than 150 mL/m², indexed RV end-systolic volume greater than 80 mL/m², RV ejection fraction less than 47% and/or left ventricular ejection fraction less than 55%. Percutaneous Melody valve implantation (Medtronic, Inc, Minneapolis, Minnesota, USA) is considered for suitable patients with moderate or severe PR or stenotic (greater than 35 mm Hg gradient) RV to pulmonary artery conduits of greater than 16 mm diameter. We utilise transcatheter balloon arterioplasty with stent implantation in patients with moderate or severe isolated residual pulmonary artery stenosis. When catheter-mediated treatment is unsuccessful or inappropriate, surgical RV outflow tract reconstruction is often recommended when RV systolic pressure is greater than two-third systemic. We recognise that some tachyarrhythmias are promoted by severe underlying haemodynamic abnormalities, and may respond to surgical or catheter-

mediated treatments. For others, management is based on judgements made about the magnitude of the threats posed by the rhythm as compared with the risks of pharmacological treatment or device implantation. For aortic dilation after TOF repair, replacement of the ascending aorta is considered when the diameter exceeds 55–60 mm.

Demographics, cardiac and surgical histories obtained from the institutional cardiology database included patient gender, age at initial repair, age at follow-up and presence of genetic syndromes (trisomy 21, 22q deletion, other chromosome deletions). At each subsequent visit during the study timeframe, the use of diagnostic tools including history and physical (H&P), ECG, Holter (HOL) monitor, echocardiogram (Echo), MR or CT imaging (MR-CT) and stress testing was noted. The recommendations for time to next follow-up visit, and change in management/INT if any were noted. The nature of INT was categorised as (A) activity restriction, (B) drug therapy initiation or modification, (C) surgical INT or (D) catheter-based INT. To the extent that the narrative in the chart revealed the rationale for each INT, and the diagnostic tools that specifically contributed to the decision for INT, these were recorded.

Statistical analysis

Continuous variables were expressed as mean±SD and ranges; discrete variables were expressed as percentages. Threshold for statistical significance was $p<0.05$. Statistical analysis was performed using commercially available software (Minitab V.16.1, Minitab Inc, State College, Pennsylvania, USA).

RESULTS

The study population consisted of 213 patients whose 916 visits formed the database. Patient characteristics including age, gender, diagnoses, genetic syndromes and surgical history are summarised in [table 1](#). The mean age at entry into the study was 11.5 years and the mean age at initial corrective surgery was 1.35 years. The mean age at which the most recent INT was carried out was 5.2 years. The mean recommended follow-up interval was 9.44±6.5 months (IQR 4–12 months) and the actual follow-up occurred at 11.7 months.

Interventions

Of 916 visits, 123 (13.43%) visits resulted in at least one INT. Of 138 INTs ([table 2](#)), catheter-based INT was most frequent (n=54), followed by surgical management (n=47) and medical therapy (n=32). Activity restriction was the least common INT (n=5).

[Table 3](#) lists the exact type of INTs separately for the paediatric and adult visits.

[Table 4](#) summarises each category of INT and how they were attributed to each diagnostic tool. [Table 5](#) summarises all visits in which INT followed, and lists the number of tool applications per patient year of

Table 1 Patient characteristics and surgical history

| | |
|--------------------------------|-------------|
| Diagnosis | |
| TOF (n) | 193 |
| PA-VSD (n) | 20 |
| Gender | |
| Male (n) | 130 |
| Female (n) | 83 |
| Genetic syndrome | |
| Trisomy 21 (n) | 7 |
| 22q11 Deletion (n) | 15 |
| Other (n) | 13 |
| Initial surgery | |
| Palliative shunt (n) | 35 |
| Primary repair (n) | 178 |
| Age (years)±SD | |
| Mean age at corrective surgery | 1.35±2.91 |
| Mean age at entry into study | 11.53±11.93 |
| Mean age at most recent INT | 5.2±9.74 |

INT, intervention; TOF, tetralogy of Fallot; PA-VSD, pulmonary atresia-ventricular septal defect.

observation, and the number of INTs attributable, at least in part, to the application of each tool. The most frequently applied tool was H&P, followed by Echo, HOL, ECG, MR-CT and stress test (table 5).

Reasons for INT in adults that were attributed to change in symptoms or physical examination were: subjective fatigue, shortness of breath and exercise intolerance (n=23), fast or irregular heart rate (n=12), and pharmacological INT for pregnancy (n=2) or hypertension (n=2). Among paediatric INT, reasons were subjective fatigue, shortness of breath and exercise intolerance (n=25), fast or irregular heart rate (n=2), hypertension (n=1) or cyanosis (n=1). Eighteen INTs (10 paediatric and 8 adults) were attributed to objective changes in exercise capacity measured by the stress test. Forty INTs (11 adult, 29 paediatric) were attributed to valvular dysfunction; 44 INTs (21 adults, 23 paediatric) for RV dilation on MRI and 14 INTs (4 adults, 10 paediatric) for cardiac chamber dysfunction. INTs were attributed to branch PA stenosis noted on Echo/MRI in 16 patients (all paediatric).

Diagnostic tools and their yield

History and physical examination

All 916 (100%) patient visits had a H&P examination; 123 (13.4%) visits resulted in an INT. The H&P contributed to the decision to intervene in 58(47.2%) of the visits where such a decision was made.

Table 2 Patient visits and types of intervention

| | | |
|-------------------------|-------|----------------------|
| Total visits | n=916 | |
| Visits resulting in INT | n=123 | 13.43% of all visits |
| Types of INTs | n=138 | |
| Surgery | 47 | 38.2% of INTs |
| Catheter-based | 54 | 43.9% of INT |
| Medical therapy | 32 | 26% of INTs |
| Activity restriction | 5 | 4% of INTs |

INT, intervention

ECG, HOL and stress test

ECG was applied in 137 (15%) visits, of which 22 visits (16.1%) resulted in an INT. The ECG findings contributed to the INT in 2 (1.6%) visits where such a decision was made. HOL was obtained in 188 (20.5%) of the total patient visits. Of these 188 visits, 36 (19.1%) resulted in INTs. The HOL contributed to the decision to intervene in 14 (11.3%) of all visits where such a decision was made. Stress test was utilised as an investigational tool in 101 (11%) of the total patient visits, and of those visits, 31 (30.7%) resulted in a change in management. The stress test contributed to the INT in 11 (8.9%) of all the visits where such a decision was made.

Imaging tests

Six hundred and fifty-two (71.2%) of the total visits involved Echo as an investigational tool, of which 90 visits (13.8%) resulted in an INT. The Echo findings contributed to the INT in 66 (53.7%) of all the visits where such a decision was made. MR-CT was obtained in 129 (14.1%) of visits, 42 (32.6%) visits resulted in an INT and MR-CT contributed to the INT in 37 (30.1%) visits.

DISCUSSION

Residual haemodynamic burden is common after TOF repair, and may include PR, tricuspid regurgitation, RV dilation or dysfunction, residual shunts, or obstruction of the RV outflow tract or pulmonary artery branches.^{13 14} The threat of atrial and ventricular tachyarrhythmias is also significant.^{11 12 15} Long-standing PR has been an active recent research focus as it is considered a reversible cause of RV dilation. With mounting evidence that PVR is most useful prior to the onset of frank RV dysfunction, there is unsettled debate surrounding the ideal timing. In this relatively ambiguous clinical landscape, cardiologists must select the appropriate tools and schedule for surveillance of these patients so as to intervene when it is in their best interest. With an array of diagnostic tools available, and a counterbalancing concern over health-care costs,^{16 17} the question of optimal frequency of clinical follow-up visits and the intensity of the testing performed at each is very relevant.

So far, there is insufficient data to allow a cardiologist to balance the costs and benefits of the means of clinical surveillance of the patient with surgically modified TOF. Guidance for how frequently these patients should be seen and what tests should be ordered is therefore largely derived from expert consensus. The American College of Cardiology/American Heart Association guidelines for management of adults with congenital heart disease (CHD) state that all patients with repaired TOF should have regular follow-up with a cardiologist with expertise in adult CHD.⁷ While the frequency of follow-up is typically annual, this may be modified based on severity and type of residua. Other recommendations include annual surveillance with ECG, assessment of RV function and periodic exercise testing for patients with

Table 3 Specific interventions categorised by pediatric versus adult

| Type of INT | INT |
|----------------------|--|
| Surgery | |
| Adult n=12 | 10 surgical PVR 1 tricuspid valve repair with right atrial reduction 1 implantable cardioverter defibrillator placement |
| Ped n=35 | 20 surgical PVR 1 aortic valve repair 14 right ventricular outflow tract reconstructions |
| Catheter-based | |
| Adult n=13 | 4 transcatheter PVR 4 electrophysiological studies 5 diagnostic catheterisations |
| Ped n=41 | 3 transcatheter PVR 15 diagnostic catheterisations 4 electrophysiological studies 18 pulmonary arterioplasty procedures 1 endomyocardial biopsy for unexplained LV dysfunction |
| Medical therapy | |
| Adult n=18 | 1 anticoagulation regimen change 2 bronchodilator therapy 6 antihypertensive therapy 8 antiarrhythmic therapy 1 diuretic regimen adjustments |
| Ped n=14 | 1 medication change for frequent premature ventricular complexes 2 antiarrhythmic medication changes 4 diuretic regimen adjustments 1 pulmonary vasodilator therapy 6 ACE inhibitor therapy for worsening LV dysfunction |
| Activity restriction | |
| Adult n=2 | 2 activity restrictions pending exercise stress test for palpitation Work up |
| Ped n=3 | 2 for frequent ectopy on Holter 1 patient with moderate ventricular hypertrophy |

INT, intervention; LV, left ventricular; PVR, pulmonary valve replacement.

pacemakers or automatic implantable cardiac defibrillators. Periodic HOL monitoring is believed to be helpful, and is also recommended in routine follow-up, but its frequency should be individualised depending on the haemodynamics and level of clinical suspicion of arrhythmia.

Current European and Canadian guidelines have similar recommendations for annual clinical and echocardiographic follow-up for the majority of patients with TOF (less frequently for those with less severe, stable

disease) and also recommend MR evaluation at intervals guided by severity and nature of the individual patient's pathology.^{8,9} Helpful as these guidelines might be, they are not nearly so strong or specific as the circumstances in general adult cardiology for which appropriate use criteria have been published for both Echo and cardiac CT.^{18,19} Guidelines written by experts who recognise the clinical heterogeneity of the surgically modified TOF population are broad enough to leave latitude for rather broad variability in practice patterns, which could lead

Table 4 Categories of intervention with attribution to each diagnostic tool

| | Surgery (N=47) | Catheter-based (N=54) | Medical therapy (N=32) | Activity restriction (N=5) |
|---------------------------------|----------------|-----------------------|------------------------|----------------------------|
| INT attributable to H&P, n | 20 | 32 | 12 | 3 |
| INT attributable to ECG | 2 | 0 | 0 | 0 |
| INT attributable to Echo | 37 | 43 | 9 | 3 |
| INT attributable to stress test | 5 | 10 | 3 | 0 |
| INT attributable to CT-MR | 13 | 33 | 4 | 0 |
| INT attributable to Holter | 5 | 6 | 8 | 0 |

Echo, echocardiogram; H&P, history and physical; INT, intervention.

Table 5 The proportions of visits at which each tool was applied and the number of INTs attributable, at least in part, to each tool

| Tool | Number of times tool applied N, (% of total number of visits) | Tool applications per patient-year of observation | Number of times tool contributed to INT decision N, (% of contributions per tool application)* | Percentage of total INT decisions to which tool contributed |
|-------------|---|---|--|---|
| H&P | 916 (100) | 1.02 | 58 (6.3) | 42.0 |
| Echo | 652 (71.2) | 0.73 | 66 (10.1) | 47.8 |
| Holter | 188 (20.5) | 0.21 | 14 (7.4) | 10.1 |
| ECG | 137 (15) | 0.15 | 2 (1.5) | 1.4 |
| MR-CT | 129 (14.1) | 0.14 | 37 (28.7) | 26.8 |
| Stress test | 101 (11) | 0.11 | 11 (10.9) | 8.0 |

*More than one tool may contribute to a decision. Some visits are associated with more than one INT.
Echo, echocardiogram; H&P, history and physical; INT, intervention.

to either overutilisation or underutilisation of healthcare services in this population.

The 1.02 follow-up visits per patient-year of observation in this series is in remarkable agreement with published guidelines, but only 15% of these encounters resulted in a change in therapy. These INTs were most commonly surgical or catheter-mediated, but a significant minority were changes in medical management. It is beyond the scope of this report to judge whether the ratio of roughly seven visits to one INT is too high or low, but it might be deemed appropriate since it is the result of general adherence to the expert consensus of how often these patients should be seen.

Echo was utilised at the majority of the visits in this series (there were 0.73 Echos per patient-year of observation), it contributed to close to half the decisions to change management overall, and yielded such a contribution approximately 10% of the times it was obtained. MR or CT imaging was arranged far less frequently than Echo in this series, 0.14 MR or CT examinations per patient year of observation. Per test it more often contributed to a decision to change clinical management than did Echo. These differences probably reflect the ease with which Echo can be arranged, which lends itself to be applied more broadly as a screen in this population. MR or CT can be cumbersome to arrange, but provide more precise RV volumetrics, so these are apparently reserved for a targeted group of patients for whom INT to relieve RV volume overload is more likely.

HOL monitor was carried out at a rate of 0.21 recordings per patient-year of observation, but only contributed to decisions for management change about 7% of the times it was done. This suggests that it was primarily used as a periodic screen for the known electrophysiological complications of surgically modified TOF. Stress test, on the other hand, was less frequently obtained, but resulted in a higher rate of contribution to INT, which would fit with a pattern of targeted testing, done 'for cause' in selected patients perceived to be more likely in need of INT.

Contrary to published guidelines, the standard ECG was not frequently obtained in this series. Seldom could

the case be made, retrospectively at least, that the ECG contributed to decisions to intervene. These data should be interpreted with caution, as the results of the ECG (eg, exceptionally wide QRS) could trigger further investigation (like MR) which might, in turn, prompt an INT. The indirect role of the ECG in a decision to intervene, therefore, might not be explicit enough to be recognised in a chart review such as this, leading to an underestimate of its value.

In summary, this survey of care for surgically modified TOF reveals that a simple list of recommended surveillance modalities, and the frequency with which they ought to be obtained is an oversimplification, which perhaps with good reason, would not reflect current practice. There are frequently applied modalities that can be thought of as screens, some of which (Echo and HOL) are higher yield than others (H&P). Other less frequently applied modalities are best thought of as targeted testing, with MR/CT having very high yield, and stress testing more moderate yield.

The yield of targeted testing could, in theory, be enhanced by risk stratification to limit the portion of the patient population in which tests are applied.²⁰ There has been substantial work to identify risk factors for major adverse events such as death, ventricular tachycardia and heart failure in surgically modified TOF. A number of predictors have emerged, including older age at repair, prolonged QRS duration,⁶ sustained ventricular tachycardia,²¹ and the haemodynamic consequences of severe PR leading to RV dilation,²² ventricular dysfunction,^{5 22} and regional wall motion abnormalities.²³ Risk stratification in repaired TOF is presently based on retrospective studies and remains a work in progress. However, it may be possible to develop risk stratification into an integrated model capable of refining outpatient practices to enhance surveillance of those at higher risk, and limit testing among lower risk patients who would have minimal potential to benefit. The result would be an increased efficiency of use of diagnostic modalities and more effective resource utilisation.

Development and implementation of a standardised Clinical Assessment and Management Plan (SCAMP)^{24 25}

for outpatient follow-up of repaired TOF would be one method to explore this further. SCAMPs are innovative quality improvement initiatives that actively collect data on deviations from the standardised algorithms that occur in actual practice. A standardised algorithm for follow-up of repaired TOF could be established, and then periodic analysis of patterns of deviation from the algorithm could help identify subgroups of patients for targeted testing. Ultimately, by iterative incorporation of the systematically productive deviations into the algorithm, a more comprehensive algorithm is produced, from which there will be fewer practice variations, and by which patient care will be enhanced.

LIMITATIONS

This is a retrospective study. The only outcome studied was active management change, whereas clinically important decisions not to change management were not accounted for in this design. The patient population was heterogeneous, and included many potential confounders, ranging from a variety of insurance types and financial circumstances, to other non-cardiac medical conditions, chromosomal anomalies, diverse ages at intra-cardiac repair and at entry into the study, inconsistent history of prior palliative shunts and inconsistent history of subsequent surgical and catheter-mediated cardiac procedures. While this heterogeneity is an advantage in the sense that it reflects the clinical realities of surgically modified TOF, the influences of the many clinical factors on the frequency of clinical follow-up and the application of diagnostic modalities could not be effectively addressed. Attribution of the decision to the information gathered by one or more of the diagnostic tools was done with care, but when derived from record review, is recognised to be imperfect. Finally, there are no safeguards to assure that the clinical INTs in this series were always appropriate. While we believe that most times they were, and therefore the tests on which they are based were of positive value to the patient, we acknowledge that it is a leap to conclude that a diagnostic modality is good just because it leads to an INT.

CONCLUSIONS

Although the results of this study must be understood in light of the limitations, it does contain several valuable observations. (1) Clinical follow-up of surgically modified TOF at approximately yearly intervals resulted in management changes at about 15% of the visits. (2) Echo and HOL monitoring served primarily in a screening capacity, and although they were not utilised as frequently as clinical H&P in this series, they more often yielded relevant information to guide decisions to intervene. (3) Stress testing and MR/CT were applied as targeted testing and in this limited, non-screening role had high yield in the decision to intervene. (4) There was low utilisation of ECG in this series and major impact on INT yield could not be demonstrated.

Acknowledgements The authors appreciate the assistance of Carolyn Chamberlain, RN BSN MPH. SK receives support from the American Heart Association and the Children's Hospital Foundation.

Contributors AVH and SK designed the study protocol, analysed the data and drafted the manuscript. DAD participated in the study design and helped with the statistical analysis. RLS helped to draft the manuscript. All authors read and approved the final manuscript.

Competing interests None declared.

Ethics approval University of Nebraska.

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement No additional data are available.

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