Cardiol Young 2004; 14: 118–121

ISSN 1047-9511

Editorial Comment

Some thoughts about the "lesser" ventricle in the "greater" circulation

Robert M. Freedom

Professor of Pediatrics, Pathology and Medical Imaging, The University of Toronto Faculty of Medicine; Director Emeritus, Division of Cardiology, The Hospital for Sick Children, Toronto, Canada

THE NATURAL AND MODIFIED HISTORY OF THE patient with congenitally corrected transposition, more recently referred to by some as double discordance because of the discordant connections found at both the atrioventricular and ventriculoarterial junctions, is indeed a guarded and perilous one.[1–7] From a clinical perspective, the outcomes of these patients are closely related to the frequent co-existing cardiac anomalies, particularly ventricular septal defect and obstruction of the sub-pulmonary outflow tract from the morphologically left ventricle, and the anatomy of the specialized conduction tissue, which underscores the predisposition to spontaneous and acquired complete heart block.[1–8] Perhaps the "Achilles Heels" of this malformative complex, nonetheless, are the form and function of the systemic morphologically right ventricle and the morphologically tricuspid valve.[1–5,7] Because of many clinical observations documenting attrition of patients with congenitally corrected transposition both before and after surgery, indeed worsening in some even after physiological surgical repair,[1–4,7,9–22] it is not surprising that many have questioned the long-term ability of the morphologically right ventricle to function as the systemic ventricle in these patients and have thus sought alternatives to physiological repair. The surgical innovation of repositioning the morphologically left ventricle into the systemic circulation, and the morphologically right ventricle to the lesser circulation, of the patient with double discordance began with the experience of Ilbawi and colleagues in 1990.[23] Their novel approach was the first to achieve a type of double switch operation at both atrial and ventricular levels. Similar concerns about the right ventricle, of course, are germane to the patient with concordant atrioventricular but discordant ventriculoarterial connections who has undergone an atrial form of physiological repair.[24] Since the systemic morphologically right ventricle in patients with double discordance, or indeed in "regular" transposition after physiological repair, is vulnerable or susceptible to early failure, what are the underlying mechanisms contributing to this?

Considerable data has been marshalled to either support or refute, indeed largely to refute, the ability of the systemic morphologically right ventricle, the lesser ventricle, to function normally in the greater systemic circulation of the patient with double discordance. A number of accounts have been given of patients with double discordance surviving to the 7th, 8th and 9th decades of life,[25–34] the inference of these observations being that the morphologically right ventricle can indeed function long-term as the systemic ventricle. Yet, despite these anecdotal cases of longevity, there is increasing clinical evidence, though not unanimity, that the morphologically right ventricle does not perform well in the medium-to-long-term as a systemic ventricle in relatively large cohorts of patients with double discordance. These observations are predicated on the many longitudinal studies of these patients published primarily in the past two and a half decades.[1,7,9–21] Furthermore, most such longitudinal studies indicate that both moderate-to-severe tricuspid regurgitation, and poor right ventricular function, are arbiters of poor outcome amongst patients with double discordance.[1,7,9–21,35,36] The exact prevalence of abnormalities of the morphologically tricuspid valve in these patients is subject to discussion and debate. Some anatomical studies report a prevalence of abnormalities in

Correspondence to: Robert Freedom, Professor of Pediatrics, Pathology and Medical Imaging, The University of Toronto Faculty of Medicine; Director Emeritus, Division of Cardiology, The Hospital for Sick Children, Toronto, Canada. Tel: 902 532 2182; Fax: 902 532 0832; E-mail: rfreedom@granvilleferry.com

Accepted for publication 22 December 2003

between half and nine-tenths of patients, while in other clinical studies, the prevalence was lower at 44%.[2,3,35–37] Acar and colleagues have found that important functional and anatomical abnormalities of the tricuspid valve are more common in patients with double-discordance who have either an intact ventricular septum or associated ventricular septal defect when compared to a group with associated ventricular septal defect and pulmonary stenosis.[36] Van Praagh and his colleagues have placed into perspective those anatomic features of the morphologically right ventricle and the tricuspid valve in the setting of double discordance that jeopardize these patients.[38] These include the nature of the coronary circulation, the disposition of the papillary muscles, and the geometric integrity of the tricuspid as opposed to the mitral valve when guarding a circular systemic ventricular orifice.[38] Some investigations of outcome suggest that the functional deterioration of the systemic right ventricle begins with chronic volume loading from tricuspid regurgitation, and that treatment should be aimed at maintaining tricuspid valvar competence.[35] Other studies are less certain or persuasive about the relationship between right ventricular dysfunction and tricuspid regurgitation, raising the spectre of the "chicken and egg" phenomenon.[14,17–19]

Acknowledging that systemic right ventricular dysfunction and tricuspid regurgitation are interlinked, indeed comorbid, and that both adversely affect the outcomes of these patients, it becomes important further to define the etiology of the systemic right ventricular dysfunction in these patients. Thus, there has been a long interest in the myocardium of the systemic right ventricle in patients with double discordance, with many studies using radionuclide imaging.[39–45] Some years ago, Hornung and colleagues,[46] using Sestamibi scanning, reported that patients with double discordance have a high prevalence of myocardial perfusion defects, with consequent regional abnormalities of motion of the ventricular walls, and hypertrophy and impaired ventricular performance. They went on to conclude that ischemia and infarction are important arbiters of systemic right ventricular failure in these patients. Espinola-Zavaleta and colleagues extend these observations in this issue of *Cardiology in the Young*.[47] They studied a modest-sized cohort of adults with double discordance using both contrast echocardiography and equilibrium radionuclide ventriculography and gated single-photon emission computed tomography with Technetiumc-99 m sestamibi. Like Hornung and his colleagues,[46] they also found persistent and ischemic perfusion defects, suggesting that these defects, together with chronic volume overload from tricuspid regurgitation, are the determining factors of right ventricular dysfunction in these patients. Tulevski and his colleagues,[48] also in this issue, have studied global and regional right ventricular function in patients with double discordance using cardiac magnetic resonance imaging, at rest and during dobutamine stress. In this study of again only a modest cohort of patients, they found that ischemia of the right ventricular myocardium contributes to the development of right ventricular dysfunction.[48] These authors found that the morphologically right ventricle, when subjected to systemic pressures in patients with double discordance, shows extensive and global hypertrophy compared to the thin wall of the right ventricle when functioning under normal pressure. Hypertrophy places additional demand on the supply through the right coronary artery, and progressive ischemia likely develops, leading to ventricular dysfunction.[49] If myocardial ischemia and infarction of the abnormally hypertrophied systemic right ventricle contribute to the dysfunction of the right ventricle, then the observations of Hauser and colleagues[50] are equally germane. They have shown that patients with double discordance have impaired myocardial blood flow and coronary flow reserves of the systemic morphologically right ventricle.[50] It is hardly surprising in the light of these observations concerning anatomical and clinical issues relative to longitudinal outcome and the state of the ventricular myocardium and its arterial supply that the desirable evolution from physiological to anatomic repair of patients with double discordance has now been widely adopted.[23,51–56] We should not be surprised that, amongst patients with a concordant atrioventricular but discordant ventriculoarterial connections who have undergone a physiological atrial repair by means of the Mustard or Senning procedures, findings of myocardial ischemia and infarction using similar methodologies have also been identified, providing one explanation for the right ventricular dysfunction and failure also seen in these patients.[24,57–63] With these increasingly sophisticated observations, it becomes clear why the "lesser" ventricle does not fare well in the "greater" circulation. They support strongly the notion that, at least for some patients with double discordance, surgical strategies to reposition or restore the lesser ventricle into the lesser pulmonary circulation should likely be employed, or at least considered.[64–67]

References

1. Freedom RM, Yoo SJ, Williams WG. Conditions with Double Discordance (Congenitally Corrected Transposition of the Great Arteries). In: Freedom RM, Yoo SJ, Mikailian H, Williams WG (eds). The Natural and Modified History of Congenital Heart Disease. Blackwell Publishing Co., Futura Division, Oxford, UK, 2004, pp 356–365.
2. Losekoot TG, Anderson RH, Becker AE, Danielson GK, Soto B. Congenitally Corrected Transposition. Churchill Livingstone, Edinburgh, 1983, pp 3–190.

https://doi.org/10.1017/S1047951104002021 Published online by Cambridge University Press

3. Losekoot TG, Becker AE. Discordant atrioventricular connexion and congenitally corrected transposition. In: Anderson RH, Macartney FJ, Shinebourne EA, Tynan M (eds). Paediatric Cardiology. Churchill Livingstone, Edinburgh, 1987, pp 867–888.
4. Freedom RM, Mawson J, Yoo S-J, Benson LN. Congenital Heart Disease: Textbook of Angiocardiography. Futura Publishing Co., Armonk, NY, 1997, pp 1017–1131.
5. Acar P, Bonnet D, Aggoun Y, Bonhoeffer P, Villain E, Sidi D, Kachaner J. [Double discordances with ventricular septal defect and pulmonary obstruction. A study of 72 cases.] [Doubles discordances avec communication interventriculaire et obstacle pulmonaire. Etude de 72 cas.] Arch Mal Coeur Vaiss 1997; 90: 625–629.
6. Van Praagh R. What is congenitally corrected transposition? N Engl J Med 1970; 282: 1097–1098.
7. Warnes CA. Congenitally corrected transposition: the uncorrected misnomer. J Am Coll Cardiol 1996; 27: 1244–1245.
8. Anderson RH, Becker AE, Arnold R, Wilkinson JL. The conducting tissues in congenitally corrected transposition. Circulation 1974; 50: 911–924.
9. Bjarke BB, Kidd BSL. Congenitally corrected transposition of the great arteries: a clinical study of 101 cases. Acta Paediatr Scand 1976; 65: 153–160.
10. Huhta JC, Danielson GK, Ritter DG, Ilstrup DM. Survival in atrioventricular discordance. Pediatr Cardiol 1985; 6: 57–62.
11. Lundstrom U, Bull C, Wyse RK, Somerville J. The natural and "unnatural" history of congenitally corrected transposition. Am J Cardiol 1990; 65: 1222–1229.
12. McGrath LB, Kirklin JW, Blackstone EH, Pacifico AD, Kirklin JK, Bargeron LM Jr. Death and other events after cardiac repair in discordant atrioventricular connection. J Thorac Cardiovasc Surg 1985; 90: 711–728.
13. Voskuil M, Hazekamp MG, Kroft LJ, Lubbers WJ, Ottenkamp J, van der Wall EE, Zwinderman KH, Mulder BJ. Postsurgical course of patients with congenitally corrected transposition of the great arteries. Am J Cardiol 1999; 83: 558–562.
14. Beauchesne LM, Warnes CA, Connolly HM, Ammash NM, Tajik AJ, Danielson GK. Outcome of the unoperated adult who presents with congenitally corrected transposition of the great arteries. J Am Coll Cardiol 2002; 40: 285–290.
15. Connelly MS, Liu PP, Williams WG, Webb GS, Robertson P, McLaughlin PR. Congenitally corrected transposition of the great arteries in the adult. Functional status and complications. JACC 1996; 27: 1238–1243.
16. Presbitero P, Somerville J, Rabajoli F, Stone S, Conte MR. Corrected transposition of the great arteries without associated defects in adult patients: clinical profile and follow up. Br Heart J 1995; 74: 57–59.
17. Yeh T, Connelly MS, Coles JG, Webb GD, McLaughlin PR, Freedom RM, Cerrito PB, Williams WG. Atrioventricular discordance: results of repair in 127 patients. J Thorac Cardiovasc Surg 1999; 117: 1190–1203.
18. Graham TP, Bernard YD, Mellen BG, Celermajer D, Baumgartner H, Cetta F, Connolly HM, Davidson WR, Dellborg M, Foster E, Gersony WM, Gessner IH, Hurwitz RA, Kaemmerer H, Kugler JD, Murphy DJ, Noonan JA, Morris C, Perloff JK, Sanders SP, Sutherland JL. Long-term outcome in congenitally corrected transposition of the great arteries: a multi-institutional study. J Am Coll Cardiol 2000; 36: 255–261.
19. Biliciler-Denktas G, Feldt RH, Connolly HM, Weaver AL, Puga FJ, Danielson GK. Early and late results of operations for defects associated with corrected transposition and other anomalies with atrioventricular discordance in a pediatric population. J Thorac Cardiovasc Surg 2001; 122: 234–241.
20. Jahangiri M, Redington AN, Elliott MJ, Stark J, Tsang VT, de Leval MR. A case for anatomic correction in atrioventricular discordance? Effects of surgery on tricuspid valve function. J Thorac Cardiovasc Surg 2001; 121: 1040–1045.
21. Rutledge JM, Nihill MR, Fraser CD, O'Brian Smith E, McMahon CJ, Bezold LI. Outcome of 121 patients with congenitally corrected transposition of the great arteries. Pediatr Cardiol 2002; 23: 137–145.
22. Cowley CG, Rosenthal A. Congenitally corrected transposition of the great arteries: the systemic right ventricle. Prog Pediatr Cardiol 1999; 10: 31–35.
23. Ilbawi MN, DeLeon SY, Backer CL, Duffy CE, Muster AJ, Zales VR, Paul MH, Idriss FS. An alternative approach to the surgical management of physiologically corrected transposition with ventricular septal defect and pulmonary stenosis or atresia. J Thorac Cardiovasc Surg 1990; 100: 410–415.
24. Freedom RM, Yoo SJ, Williams WG. Complete transposition of the great arteries: history of palliation and atrial repair. In: Freedom RM, Yoo SJ, Mikailian H, Williams WG (eds). The Natural and Modified History of Congenital Heart Disease. Blackwell Publishing Co., Futura Division, Oxford, UK, 2004, pp 306–322.
25. Schwab JO, Ehlgen A, Sommer T. Congenitally corrected transposition of the great arteries in a 70-year-old woman diagnosed using single-detector helical CT. Am J Roentgenol 2003; 181: 598.
26. Lieberson AD, Schumacher RR, Childress RH, Genovese PD. Corrected transposition of the great vessels in a 73-year-old man. Circulation 1969; 39: 96–99.
27. Roffi M, de Marchi SF, Seiler C. Congenitally corrected transposition of the great arteries in an 80 year old woman. Heart 1998; 79: 622–623.
28. Ikeda U, Furuse M, Suzuki O, Kimura K, Sekiguchi H, Shimada K. Long-term survival in aged patients with corrected transposition of the great arteries. Chest 1992; 101: 1382–1385.
29. Sasaki O, Hamada M, Hiasa G, Ogimoto A, Ohtsuka T, Suzuki M, Hara Y, Shigematsu Y, Araki S, Hiwada K. Congenitally corrected transposition of the great arteries in a 65-year-old woman. Jpn Heart J 2001; 42: 645–649.
30. Misumi I, Kimura Y, Hokamura Y, Yamabe H, Ueno K. Congenitally corrected transposition of the great arteries with a patent foramen ovale in an 81-year-old man – a case report. Angiology 1999; 50: 75–79.
31. Attie F, Rijlaarsdam M, Zabal C, Buendia A, Vargas-Barron J. [Corrected transposition of the great arteries in patients over 65.] [Transposicion corregida de las grandes arterias en pacientes mayores de 65 anos.] Arch Inst Cardiol Mex (Mexico) 1995; 65: 57–64.
32. Sumner AD, Campbell JA, Sorrell VL. Echocardiographic diagnosis of congenitally corrected transposition of the great arteries in a 76-year-old woman. Am J Geriatr Cardiol 2001; 10: 162–163.
33. Yamazaki I, Kondo J, Imoto K, Suzuki S, Ichikawa Y, Yanagi H, Takanashi Y. Corrected transposition of the great arteries diagnosed in an 84-year-old woman. J Cardiovasc Surg 2001; 42: 201–203.
34. Ikeda U, Kimura K, Suzuki O, Furuse M, Natsume T. Long-term survival in "corrected transposition". Lancet 1991; 337: 180–181.
35. Prieto LR, Hordof AJ, Secic M, Rosenbaum MS, Gersony WM. Progressive tricuspid valve disease in patients with congenitally corrected transposition of the great arteries. Circulation 1998; 98: 997–1005.
36. Acar P, Sid D, Bonnet D, Aggoun Y, Bonhoeffer P, Kachaner J. Maintaining tricuspid valve competence in double discordance: a challenge for the pediatric cardiologist. Heart 1998; 80: 479–483.
37. Allwork SP, Bentall HH, Becker AE, Cameron H, Gerlis LM, Wilkinson JL, Anderson RH. Congenitally corrected transposition of the great arteries. Morphologic study of 32 cases. Am J Cardiol 1976; 38: 910–923.
38. Van Praagh R, Papagiannis J, Grunenfelder J, Bartram U, Martanovic P. Pathologic anatomy of corrected transposition of the great arteries: medical and surgical implications. Am Heart J 1998; 135: 772–785.

39. Benson LN, Burns R, Schwaiger M, Schelbert HR, Lewis AB, Freedom RM, Olley PM, McLaughlin P, Rowe RD. Radionuclide angiographic evaluation of ventricular function in isolated congenitally corrected transposition of the great arteries. Am J Cardiol 1986; 58: 319–324.
40. Bajwa N, Bianco JA, Stone CK. Thallium myocardial scintigraphy in congenitally corrected transposition of the great arteries. J Nucl Med 1991; 32: 1611–1613.
41. Abdel-Dayem HM, Hassan IM, Mousa MA, et al. Thallium-201 myocardial imaging in congenitally corrected transposition of the great arteries. Nucl Med Commun 1986; 11: 564–567.
42. Hornung TS, Bernard EJ, Celermajer DS, Jaeggi E, Howman-Giles RB, Chard RB, Hawker RE. Right ventricular dysfunction in congenitally corrected transposition of the great arteries. Am J Cardiol 1999; 84: 1116–1119.
43. Dodge-Khatami A, Tulevski II, Bennink GB, Hitchcock JF, de Mol BA, van der Wall EE, Mulder BJ. Comparable systemic ventricular function in healthy adults and patients with unoperated congenitally corrected transposition using MRI dobutamine stress testing. Ann Thorac Surg 2002; 73: 1759–1764.
44. Peterson RJ, Franch RH, Fajman WA, Jones RH. Comparison of cardiac function in surgically corrected and congenitally corrected transposition of the great arteries. J Thorac Cardiovasc Surg 1988; 96: 227–236.
45. Dimas AP, Moodie DS, Sterba R, Gill CC. Long-term function of the morphologic right ventricle in adult patients with corrected transposition of the great arteries. Am Heart J 1989; 118: 526–530.
46. Hornung TS, Bernard EJ, Jaeggi ET, Howman-Giles RB, Celermajer DS, Hawker RE. Myocardial perfusion defects and associated systemic ventricular dysfunction in congenitally corrected transposition of the great arteries. Heart 1998; 80: 322–326.
47. Espinola-Zavaleta N, Alexanderson E, Attié F, Muñoz Castellanos L, Dueñas R, Rosas M, Keirns C. Right ventricular function and ventricular perfusion defects in adults with congenitally corrected transposition: correlation of echocardiography and nuclear medicine. Cardiol Young 2004; 14: 174–181.
48. Tulevski II, Zijta FM, Smeijers AS, Dodge-Khatami A, van der Wall EE, Mulder BJM. Regional and global right ventricular dysfunction in asymptomatic or minimally symptomatic patients with congenitally corrected transposition. Cardiol Young 2004; 14: 168–173.
49. Graham TP Jr, Parrish MD, Boucek RJ Jr, Boerth RC, Breitweiser JA, Thompson S, Robertson RM, Morgan JR, Friesinger CC. Assessment of ventricular size and function in congenitally corrected transposition of the great arteries. Am J Cardiol 1983; 51: 244–251.
50. Hauser M, Bengel FM, Hager A, Kuehn A, Nekalla SG, Kaemmerer H, Schwaiger M, Hess J. Impaired myocardial blood flow and coronary flow reserve of the anatomical right systemic ventricle in patients with congenitally corrected transposition of the great arteries. Heart 2003; 89: 1231–1235.
51. Imai Y, Sawatari K, Hoshino S, Ishihara K, Nakazawa M, Momma K. Ventricular function after anatomic repair in patients with atrioventricular discordance. J Thorac Cardiovasc Surg 1994; 107: 1272–1283.
52. Yamagishi Y, Imai Y, Hoshino S, Ishihara K, Koh Y, Nagatsu M, Shinoka T, Koide M. Anatomic correction of atrioventricular discordance. J Thorac Cardiovasc Surg 1993; 105: 1067–1076.
53. Yagihara T, Kishimoto H, Isobe F, Yamamoto F, Nishigaki K, Matsuki O, Uemura H, Kamiya T, Kawashima Y. Double switch operation in cardiac anomalies with atrioventricular and ventriculoarterial discordance. J Thorac Cardiovasc Surg 1994; 107: 351–358.
54. Bove EL. Congenitally corrected transposition of the great arteries: surgical options for biventricular repair. Prog Pediatr Cardiol 1999; 10: 45–49.
55. Devaney EJ, Charpie JR, Ohye RG, Bove EL. Combined arterial switch and Senning operation for congenitally corrected transposition of the great arteries: Patient selection and intermediate results. J Thorac Cardiovasc Surg 2003; 125: 500–507.
56. Bull C, Yates R, Sarkar D, Deanfield J, de Leval M. Scientific, ethical, and logistical considerations in introducing a new operation: a retrospective cohort study from paediatric cardiac surgery. BMJ 2000; 320: 1168–1173.
57. Piran S, Veldtman G, Siu S, Webb GD, Liu PP. Heart failure and ventricular dysfunction in patients with single or systemic right ventricles. Circulation 2002; 105: 1189–1194.
58. Gatzoulis MA, Walters J, McLaughlin PR, Merchant N, Webb GD, Liu P. Late arrhythmia in adults with the mustard procedure for transposition of great arteries: a surrogate marker for right ventricular dysfunction? Heart 2000; 84: 409–415.
59. Lubiszewska B, Gosiewska E, Hoffman P, Teresinska A, Rozanski J, Piotrowski W, Rydlewska-Sadowska W, Kubicka K, Ruzyllo W. Myocardial perfusion and function of the systemic right ventricle in patients after atrial switch procedure for complete transposition: long-term follow-up. J Am Coll Cardiol 2000; 36: 1365–1370.
60. Millane T, Bernard EJ, Jaeggi E, Howman-Giles RB, Uren RF, Cartmill TB, Hawker RE, Celermajer DS. Role of ischemia and infarction in late right ventricular dysfunction after atrial repair of transposition of the great arteries. J Am Coll Cardiol 2000; 35: 1661–1668.
61. Singh TP, Humes RA, Muzik O, Kottamasu S, Karpawich PP, Di Carli MF. Myocardial flow reserve in patients with a systemic right ventricle after atrial switch repair. J Am Coll Cardiol 2001; 37: 2120–2125.
62. Labbe L, Douard H, Barat JL, Broustet JP, Bordenave L, Ducassou D, Valli N, Jimenez M, Baudet E, Choussat A. [Alteration of myocardial viability and systemic ventricular dysfunction after Senning procedure.] [Alteration de la viabilite myocardique et dysfonction ventriculaire systemique apres intervention de Senning.] Arch Mal Coeur Vaiss (France) 1997; 90: 631–637.
63. Carrel T, Pfammatter JP. Complete transposition of the great arteries: surgical concepts for patients with systemic right ventricular failure following intraatrial repair. Thorac Cardiovasc Surg 2000; 48: 224–227.
64. Ohuchi H, Hiraumi Y, Tasato H, Kuwahara A, Chado H, Toyohara K, Arakaki Y, Yagihara T, Kamiya T. Comparison of the right and left ventricle as a systemic ventricle during exercise in patients with congenital heart disease. Am Heart J 1999; 137: 1185–1194.
65. Fredriksen PM, Chen A, Veldtman G, Hechter S, Therrien J, Webb G. Exercise capacity in adult patients with congenitally corrected transposition of the great arteries. Heart 2001; 85: 191–195.
66. Dyer K, Graham TP. Congenitally corrected transposition of the great arteries: Current treatment options. Curr Treat Options Cardiovasc Med 2003; 5: 399–407.
67. Mavroudis C, Backer CL. Physiologic versus anatomic repair of congenitally corrected transposition of the great arteries. Semin Thorac Cardiovasc Surg Pediatr Card Surg Annu 2003; 6: 16–26.