Seminars in Fetal & Neonatal Medicine 18 (2013) 302–310

Contents lists available at SciVerse ScienceDirect

Seminars in Fetal & Neonatal Medicine

journal homepage: www.elsevier.com/locate/siny

Diagnosis and management of life-threatening cardiac malformations in the newborn

Mats Mellander*

Department of Paediatric Cardiology, Queen Silvia Children's Hospital, Sahlgrenska University Hospital, Göteborg, Sweden

Keywords:
Aortic coarctation
Congenital heart defects
Neonatal screening
Newborn
Pulse oximetry screening
Transposition of the great vessels

SUMMARY

Approximately 1–2 per 1000 newborn babies have a cardiac defect that is potentially life-threatening usually because either the systemic or the pulmonary blood flow is dependent on a patent ductus arteriosus. A significant proportion of newborns with such cardiac defects are being discharged from well-baby nurseries without a diagnosis and therefore risk circulatory collapse and death. This risk is greatest for defects with duct-dependent systemic circulation, notably aortic arch obstruction, but is also significant in transposition of the great arteries, for example. The solution to this problem, apart from improving prenatal detection rates, is to introduce effective neonatal screening including routine pulse oximetry.

1. Introduction

Cardiac malformations are the most frequently occurring of all congenital malformations with a prevalence at live birth of around 0.8%.[1–3] Most of these defects are not directly life-threatening for the newborn. However, 10–20% of all neonates with cardiac malformations, corresponding to ~1–2 per 1000 newborns, have a cardiac defect that if undetected may cause circulatory collapse and death during the neonatal period.[4–9] Abu-Harb et al.[4] found that cardiovascular malformations accounted for 9% of all infant deaths and 43% of all infant deaths due to congenital malformations. In that study 30% of the cases were not diagnosed before death. Most of these cardiac defects are life-threatening because they have a duct-dependent systemic or pulmonary circulation. A smaller proportion are life-threatening because they cause severe cardiac failure or arterial desaturation that develop early for other reasons than ductal closure.

The purpose of this article is to review the diagnosis and management of cardiac malformations that are life-threatening to the newborn with emphasis on how to avoid circulatory collapse and death through early postnatal diagnosis when the lesion has not been diagnosed prenatally.

Primary heart disease other than cardiac malformations may also be life-threatening to the neonate, although more rarely, for example cardiac arrhythmias, cardiomyopathies, cardiac tumours and myocarditis. These are beyond the scope of this review.

2. Cardiac malformations that are potentially life-threatening to the newborn

The most widespread cardiac malformations with duct-dependent systemic circulation are coarctation of the aorta (CoA) and interrupted aortic arch (IAA), critical aortic valve stenosis (AoS) and hypoplastic left heart syndrome (HLHS). In CoA, the lower body is supplied by flow through the ductus arteriosus. In IAA type B, also the left subclavian artery and in type C the left carotid are supplied by the duct. In HLHS and AoS the circulation to both the upper and lower part of the body is dependent on flow from the right ventricle through the ductus arteriosus. Sometimes obstruction to systemic flow occurs at several levels simultaneously, for example CoA and aortic valve stenosis or a supravalvular mitral membrane, parachute mitral valve, subaortic stenosis and CoA (Shone's complex).

Duct-dependent pulmonary blood flow occurs in pulmonary atresia with intact ventricular septum (PA/IVS), critical pulmonary valve stenosis (CPS), tetralogy of Fallot (ToF) with critical subvalvar and/or valvar pulmonary stenosis, pulmonary atresia with ventricular septal defect without collateral flow to the lungs (PA/VSD), tricuspid atresia (TA) with a restrictive VSD and in some forms of severe Ebstein's anomaly. In simple transposition of the great arteries (TGA) the mixing of systemic and pulmonary venous blood is dependent mainly on a patent foramen ovale but a patent ductus arteriosus is often also necessary to optimize mixing. For the

* Tel.: +46 313434659; fax: +46 31845029.
E-mail address: mats.mellander@vgregion.se.

1744-165X
http://dx.doi.org/10.1016/j.siny.2013.04.007

purpose of this review, TGA is considered among the defects with duct-dependent pulmonary blood flow.

Some cardiac defects can be life-threatening to the newborn even if neither the systemic nor the pulmonary blood flow is duct-dependent. One such cardiac defect is total anomalous pulmonary venous return (TAPVR) with obstruction to pulmonary venous flow.

3. Missed diagnoses

A significant proportion of newborns with life-threatening cardiac defects are being discharged from well-baby nurseries without a diagnosis.[4–8,10–12] In a study based on 351 843 births in Sweden, 259 newborns had critical cardiac defects defined as those requiring surgical or catheter-based intervention before 2 months of age. The most numerous defects were CoA ($n = 64$), HLHS ($n = 51$) and TGA ($n = 64$). Out of 129 with duct-dependent systemic circulation, 38 (30%) were discharged home without suspicion of heart disease.[7] The corresponding proportion for those with duct-dependent pulmonary circulation was lower at 4 of 106. More than 40% of those discharged undiagnosed were in circulatory shock at admission. The most common diagnosis among those discharged was CoA. This was in concordance with other studies showing that aortic arch obstruction is the most frequently missed defect.[5,12] It was also shown that the proportion of newborns with a life-threatening cardiac malformation who were discharged undiagnosed increased in parallel with the increasing proportion of mothers discharged early from maternity units. One explanation of this observation is that early discharge allows less time for the baby to develop detectable signs and symptoms of heart disease while still in hospital.[7] In a later study 44% of newborns with TGA left hospital undiagnosed when pulse oximetry screening was not used, presumably as a result of even earlier discharge.[9] Thus it is clear that one important area for improvement, apart from prenatal detection rates, is the newborn screening routines.

4. Newborn screening for congenital heart defects

Early diagnosis of severe heart disease in the newborn is improved if the examiner has a high index of suspicion and an awareness of the important symptoms and physical findings.

4.1. Symptoms and signs

Increased respiratory rate and/or cyanosis are the most common presenting symptoms. On physical examination a murmur, increased precordial activity, weak or absent brachial and/or femoral pulses and poor peripheral perfusion are signs that should raise the suspicion of a cardiac defect. However, less than half of all newborns with congenital cardiac malformations have a murmur and heart murmurs do not occur more frequently in more severe heart defects.[11] Importantly, a newborn baby with a duct-dependent cardiac defect may not have any symptoms at all as long as the duct is still widely patent, and physical examination may be normal. This is especially true for defects with duct-dependent systemic circulation. In CoA and IAA, for example, femoral pulses may be normal while the duct is patent because the right ventricle supplies the descending aorta through the duct. Respiratory rate and peripheral perfusion may also be normal initially. Oxygen saturations can be normal also in the lower body because of a large left-to-right shunt at the atrial level. When the duct begins to constrict, symptoms develop gradually or rapidly depending on the rate of constriction. Respiratory rate increases, peripheral perfusion decreases and pulses become weaker or disappear. Diuresis decreases and there is increasing metabolic acidosis and if undetected eventually circulatory collapse and death.

In defects with duct-dependent pulmonary blood flow, arterial desaturation is more pronounced because of restriction to pulmonary blood flow and cyanosis is therefore more readily apparent.

4.2. Pulse oximetry screening

Pulse oximetry screening has been evaluated in a few large studies.[9,13–17] In a study in Sweden the criteria for a positive screen result was a preductal and postductal oxygen saturation <95% or a difference between the two measurements >3% on three repeated measurements.[9] The screening region (46 963 births) was compared with the rest of the referral area for pediatric cardiac surgery not using pulse oximetry screening (108 604 births). The risk of leaving hospital with undiagnosed duct-dependent circulation was 5/60 in the screening region compared with 28/100 in the other referring regions and the mortality was significantly higher among those discharged undiagnosed.[9] Importantly the false-positive rate was higher with physical examination than with pulse oximetry (1.90% vs 0.17%). Five cases were missed by combined physical examination and pulse oximetry[9] and all had aortic arch obstruction (CoA or IAA). Furthermore, 8 out of 11 cases with CoA or IAA fulfilled the criteria for a normal pulse oximetry screening test.

Thus aortic arch obstruction is not only one of the most frequent duct-dependent lesions (together with HLHS and TGA) but also the one that is most frequently missed on routine neonatal examination and unfortunately the defect most often missed by pulse oximetry screening. In addition, CoA is one of the most difficult lesions to detect on antenatal ultrasound screening.[18] Postnatally there is some promise in the so-called peripheral perfusion index (PPI).[19] PPI reflects the real-time changes in peripheral blood flow. The ratio of the pulsatile to non-pulsatile components of the infrared signal (PPI) corresponds to the relationship between pulsatile and non-pulsatile flow at the site.[19] It remains to be determined in a prospective study whether the use of this index will increase the timely postnatal detection of CoA.

TGA is also a challenge; as with CoA it is difficult to diagnose prenatally[18] unless the screening protocol includes outflow views and the three vessel and tracheal view. An improvement in prenatal detection rates has been reported from some areas.[20] In maternity wards not using pulse oximetry screening, a significant proportion will also be overlooked postnatally because the mixing at the atrial and ductal levels in some cases is so good that there will be no visible cyanosis during the first few days. In the Swedish pulse oximetry study 44% of the newborns with TGA (11/25) left the hospital undiagnosed if pulse oximetry was not used versus 0% (0/18) in the screening region.[9] One of those 11 died undiagnosed and three suffered preoperative cerebral hemorrhage or seizures. Even with neonatal pulse oximetry screening newborns with TGA are at risk if born in a hospital without specialized pediatric cardiac care. Some of these infants may have profound hypoxia from birth because of a severely restrictive foramen ovale and will need an emergency Rashkind septostomy. A prenatal diagnosis would eliminate this problem since delivery can then be planned in a specialist centre. TGA was the first cardiac defect for which it was clearly shown that a prenatal diagnosis was associated with a significantly better survival[21] and neurocognitive outcome.[20]

Pulse oximetry screening is now becoming standard care in all maternity wards in Sweden and in other countries as well, including the USA after it was endorsed by the Department of Health and Human Services in September 2011.[22,23] This initiative, together with increasing antenatal detection rates of critical cardiac malformations, should result in a decrease in the proportion of undiagnosed newborns who are discharged from the maternity wards.

5. Diagnostic methods

Any newborn baby with signs or symptoms suggestive of heart disease (which are not obviously explained by another problem) and/or positive pulse oximetry screening should have an echocardiographic examination as soon as possible. Such signs and symptoms could be a murmur, increased respiratory rate, increased precordial activity, weak or absent femoral and/or brachial pulses and poor peripheral perfusion. If the only sign is a murmur it may be acceptable to wait one day while the baby remains in the maternity ward, and, if the murmur is still there the day after, perform echocardiography before discharge. A negative pulse oximetry screening result does not completely rule out a life-threatening cardiac defect. As mentioned above, especially newborns with aortic arch obstruction may have normal saturations in both upper and lower extremities.

Echocardiography is the mainstay in the diagnostic arsenal for cardiac malformations. It will give the exact anatomic and functional diagnosis in most cases. Electrocardiography (ECG), although sometimes typical for a certain cardiac defect, is usually not helpful in the differential diagnosis. It can be completely normal also in life-threatening duct-dependent lesions, showing only the normal neonatal right heart dominance. The same is true for chest X-ray. The main diagnostic contribution from chest X-ray is to rule out concomitant pulmonary disease and to see whether pulmonary vascular markings are increased or decreased. Sometimes there is a typical cardiac silhouette in ToF, TGA or TAPVR, for example, but this will not usually provide information additional to echocardiography. Therefore, echocardiography should not be postponed in a newborn with signs or symptoms suggestive of heart disease and/or low oxygen saturation just because ECG and/or chest X-ray are normal.

Sometimes echocardiography cannot completely define the diagnosis and provide all necessary details. In CoA, for example, echocardiography may give the diagnosis but not describe the entire aortic arch in enough detail for the surgeon to plan surgery, or it may be uncertain whether the aortic narrowing found on echocardiography is of sufficient magnitude to make systemic circulation to the lower part of the body duct-dependent. In such a situation computed tomography (CT) can be helpful. Nevertheless a question may remain about duct dependency and in borderline cases it is usually necessary to discontinue prostaglandins and follow the Doppler gradient across the narrowing while the duct constricts before deciding about surgery. Anomalous pulmonary veins are sometimes difficult to map using echocardiography, and, in complex cardiac defects involving the pulmonary veins, CT and/or angiography may be required.

6. Management

If the cardiac defect is diagnosed before birth and is considered to be duct-dependent, the baby should be delivered in a tertiary centre with full pediatric cardiology/cardiac surgery service as well as neonatal intensive care in order to avoid neonatal transport and to optimize neonatal management. Cesarean section is seldom indicated because of a fetal cardiac defect. One exception may be in the case of TGA with a high risk of need for emergency Rashkind septostomy immediately after birth based on prenatal examination of the foramen ovale and ductus arteriosus.[24] Another example is total anomalous pulmonary venous return with obstruction to pulmonary venous flow. In this defect, emergency cardiac surgery may be the only option since prostaglandins will not be of benefit. However, total anomalous pulmonary venous return is still rarely diagnosed before birth.[25]

After postnatal diagnosis of a duct-dependent lesion the baby is started on i.v. prostaglandin E_1 infusion to maintain ductal patency. In case the duct has already started to constrict, a higher dose is used to open it (50–100 ng $\times$ kg^{-1} $\times$ min^{-1}) and then after an hour or so (when echocardiography confirms a widely patent duct) continued with maintenance dose (usually 5–20 ng $\times$ kg^{-1} $\times$ min^{-1}). If the presentation is with circulatory collapse because the diagnosis was not suspected before ductal constriction and there is no other obvious explanation for the deterioration, the baby should be started on prostaglandins simultaneously with resuscitation on the suspicion that it could be a duct-dependent cardiac defect. After stabilization, plans for continued management can be drawn. A period of recovery is usually advisable before surgery, ensuring restoration of cerebral, renal and liver function. In severe cases with unstable hemodynamics despite opening up the duct (usually because of myocardial dysfunction and/or atrioventricular valve regurgitation), or if the duct does not respond, treatment with extracorporeal membrane oxygenation may be necessary before surgery.

Below follows a short review of the principles of management for the most common of these cardiac defects.

7. Duct-dependent systemic circulation

7.1. Coarctation of the aorta (Fig. 1)

Once the diagnosis is established and the anatomy is clear, surgery can be planned, usually within a few days or towards the end of the first week. Interventional catheterization for primary treatment of neonatal coarctation is not performed in most centers but catheter intervention with balloon or stent dilatation has an important role in the management of recoarctations. The surgical approach depends on the degree of aortic arch hypoplasia and if the coarctation is isolated, if there is also a VSD, or if the CoA is part of a

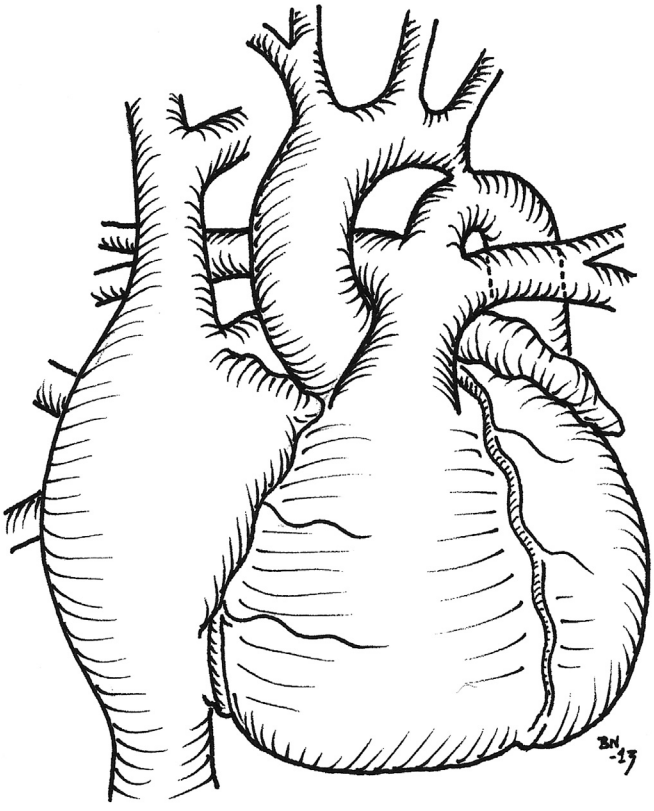

Fig. 1. Coarctation of the aorta with a patent ductus arteriosus providing flow to the lower body.

more complex defect. The surgical results in isolated coarctation are excellent and freedom from reintervention at medium term follow-up after extended resection and end-to-end anastomosis was 94% in one series.[26] Nevertheless hypertension remains a frequent complication on long-term follow-up after early repair.[27]

7.2. Interrupted aortic arch (Fig. 2)

This defect, which occurs much less frequently than CoA, is almost invariably associated with VSD and is often a part of a more complex cardiac malformation. The interruption can occur at different sites; after all arch vessels (type A), before the left subclavian artery (type B) or before the left carotid artery (type C) resulting in different patterns of peripheral pulse weakness when the duct constricts. The presentation and management is similar to CoA and results depend on associated anomalies.

7.3. Critical aortic valve stenosis (Fig. 3)

For the purpose of this review AoS is defined as a stenosis of the aortic valve that is severe enough to render the whole or part of the systemic circulation duct-dependent. Left ventricular function can be preserved with a high pressure gradient across the valve or there can be different degrees of depression of left ventricular contractility. Sometimes the left ventricle is dilated with very poor contractions and with almost no flow across the valve. The diameter of the aortic valve ring and the size of the left ventricle and mitral valve determine management. There is a spectrum of severity merging at one end into HLHS and it is sometimes difficult to judge whether a biventricular circulation is possible. Management can vary from surgical or catheter-based valvotomy in the less severe cases to so-called Ross–Konno surgery if the valve ring is too small

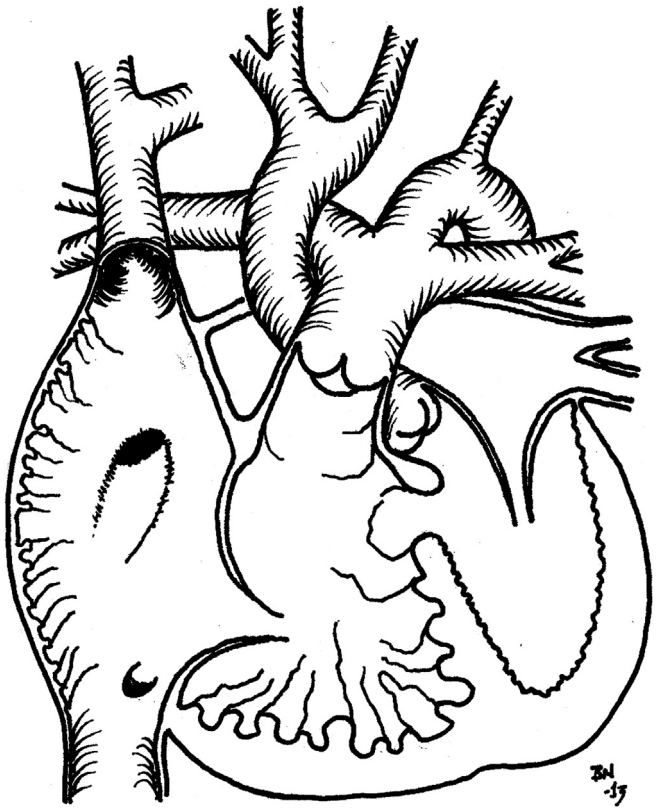

Fig. 2. Interrupted aortic arch type B (between the left carotid and subclavian arteries) with a ventricular septal defect. The descending aorta is supplied via the ductus.

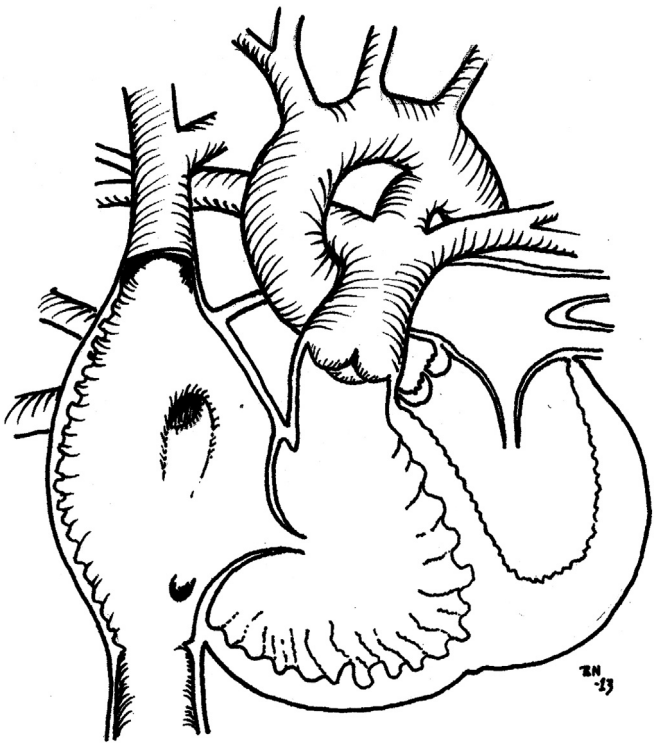

Fig. 3. Critical aortic valve stenosis with a patent ductus arteriosus.

but the left ventricle deemed capable of supporting systemic circulation. A primary decision to go for a biventricular circulation can turn out to be wrong and one may have to convert to a univentricular circulation through a Norwood procedure. Even in the most favourable cases the subsequent course includes in many cases the need for surgical or catheter-based reinterventions and finally often valve replacement. In a recently published long-term follow-up after neonatal surgical valvotomy the freedom from aortic valve replacement was 57% at 20 years.[28]

7.4. Hypoplastic left heart syndrome (Fig. 4)

In classical HLHS (aortic and mitral atresia) the whole of the systemic circulation passes through the duct and the flow through the aortic arch and ascending aorta is retrograde. If undetected, circulatory collapse will occur with ductal constriction, but even with a widely patent duct the baby may deteriorate preoperatively when pulmonary vascular resistance decreases leading to increased pulmonary flow at the expense of systemic flow. Therefore, in HLHS, oxygen administration should be avoided in order not to stimulate pulmonary vasodilatation and it will sometimes even be necessary preoperatively to intubate and hypoventilate or administer inhaled CO_2 or nitrogen to balance systemic and pulmonary perfusion. The optimal timing of Norwood surgery depends on the clinical situation but surgery is usually performed towards the end of the first week. An alternative to Norwood surgery as the first stage is a hybrid procedure including transcatheter stenting of the duct and bilateral pulmonary artery banding.[29,30] Whether results are better or worse than with Norwood surgery is not yet known, in part because this approach is often reserved for the more difficult cases.[31]

The epidemiology of HLHS is rapidly changing. Infants with this cardiac defect had a 100% mortality until William Norwood developed a surgical approach (Norwood surgery) in the 1980s which was gradually adopted by many centers beginning during

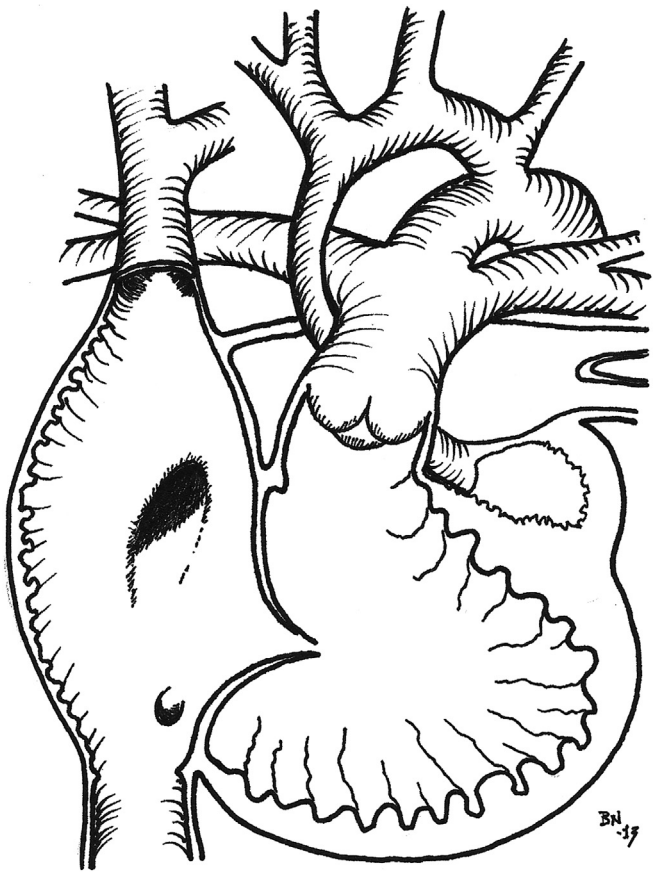

Fig. 4. Hypoplastic left heart syndrome with mitral and aortic atresia and hypoplasia of the ascending aorta. The whole of the systemic flow is supplied by the right ventricle through the ductus.

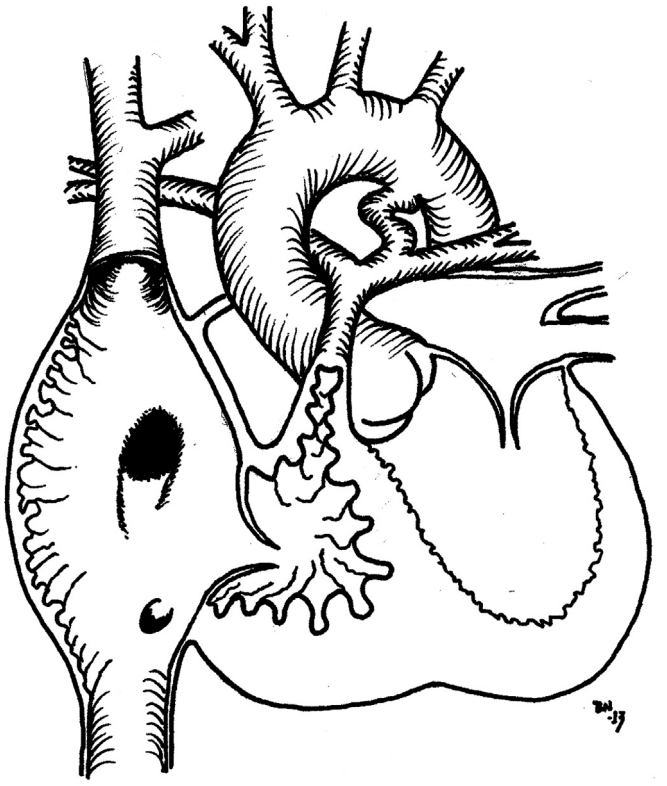

Fig. 5. Pulmonary atresia with intact ventricular septum. Pulmonary flow is via a patent ductus.

the 1990s. Five-year survival after three-stage surgery (Norwood + bidirectional Glenn procedure + total cavopulmonary anastomosis) has improved gradually and is in the range of 50–70% today in most centres.[32] In parallel with this development, prenatal screening for cardiac defects was introduced in many countries and HLHS was increasingly diagnosed prenatally, much more so than for example TGA, ToF and CoA which are more difficult to detect. In countries where pregnancy termination is an option for fetal cardiac malformation an increasing number of fetuses with HLHS are terminated. The incidence at birth of this heart defect is therefore decreasing in many countries.[33]

8. Duct-dependent pulmonary circulation

8.1. Pulmonary atresia with intact ventricular septum (Fig. 5)

In PA/IVS a left-to-right shunt across the duct provides the pulmonary flow and the baby is stabilized with prostaglandins. Subsequent management depends on right ventricular size and morphology, the tricuspid valve size and whether right ventricular-dependent coronary circulation is present. If the latter is not the case, the atresia is membranous and the right ventricle and tricuspid valve are not too hypoplastic, it may be possible to open up the atretic pulmonary valve surgically or by catheter intervention with the aim of achieving a biventricular circulation as a final result. Continued infusion of prostaglandin or a surgical systemic to pulmonary artery shunt may be necessary for a period to increase pulmonary blood flow. At the other end of the spectrum the right ventricle is diminutive and thick-walled, the tricuspid valve is severely hypoplastic and there is a muscular pulmonary atresia and often right ventricle-dependent coronary circulation. The first procedure in such a case is usually a surgical systemic-to-pulmonary artery shunt and the treatment pathway is a staged univentricular palliation. In a complete national cohort in Sweden, survival to 10 years was 68%[34] and in a recent report from Australia survival to 10 years was 80%.[35] A biventricular outcome was achieved in 62%[34] and 56%[35] of survivors respectively.

8.2. Critical pulmonary valve stenosis

Only a few cases of pulmonary valve stenosis are so severe that the newborn baby will die when the duct closes. The incidence is in the same range as PA/IVS; 10 of 259 newborns with life-threatening cardiac malformations had CPS and 12 had PA/IVS in one study.[7] The malformation belongs to the same spectrum of disease as PA/IVS and the management is similar.

8.3. Tetralogy of Fallot (Fig. 6) and pulmonary atresia with VSD (Fig. 7)

If the subvalvar and/or valvar obstruction in ToF is severe enough at birth, the pulmonary circulation will be duct-dependent and initial management is either a surgical shunt followed by complete repair later or neonatal complete repair.

In PA/VSD only those cases with central pulmonary arteries supplied only or mainly by the duct will be life-threatening to the newborn. Because of the VSD both ventricles are well developed and a systemic-to-pulmonary artery shunt operation after birth is usually the first procedure, followed by VSD closure and re-establishment of the connection between the right ventricle and pulmonary arteries with a conduit at 1–2 years.

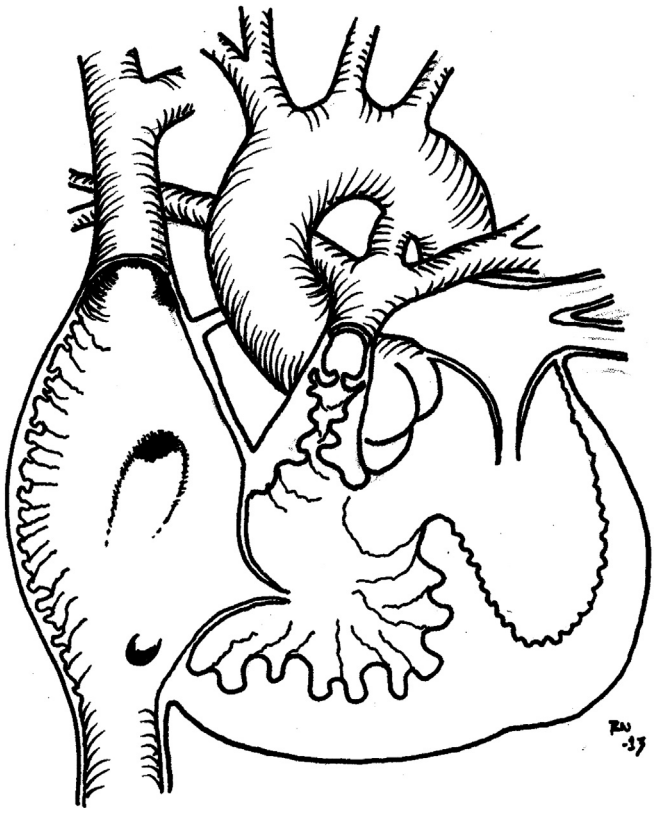

Fig. 6. Tetralogy of Fallot with subvalvar and valvar pulmonary stenosis and a ventricular septal defect. The right ventricular outflow obstruction in this case is so severe that pulmonary flow is duct-dependent.

In one study the 5-year survival after neonatal complete repair of symptomatic ToF or PA/VSD was 93% and the 5-year freedom from reoperation was 58%.[36] In a recent report of neonates with symptomatic ToF, survival was 92% and freedom from reoperation at 5 years 70–80% depending on surgical approach (shunt or repair).[37]

8.4. Tricuspid atresia (Fig. 8)

In tricuspid atresia there is usually a VSD through which blood can reach the pulmonary circulation or the systemic circulation if there is also transposition of the great arteries. If the VSD is too small, pulmonary (or systemic) blood flow will be duct-dependent. Initial management depends on anatomy. A staged univentricular palliation follows. Ten-year survival after surgery for univentricular heart with left ventricular dominance has been reported to approach 90% in a recent series.[38]

8.5. Ebstein anomaly (Fig. 9)

Ebstein anomaly is extremely variable in its severity. Only severe forms are life-threatening in the neonatal period. The malformed tricuspid valve can cause severe regurgitation and massive cardiac enlargement in fetal life. This may cause lung hypoplasia which may sometimes be so severe that neonatal survival is not possible. Even if this is not the case the right ventricle may not be able to eject blood to the pulmonary artery, the whole stroke volume regurgitates back into the right atrium, and pulmonary blood flow will be duct-dependent. It is sometimes difficult on echocardiography to determine whether this type of 'functional' pulmonary atresia is present or whether there is Ebstein anomaly plus anatomical pulmonary valve atresia. The management then is usually to wait for a few days with the baby on prostaglandins. In

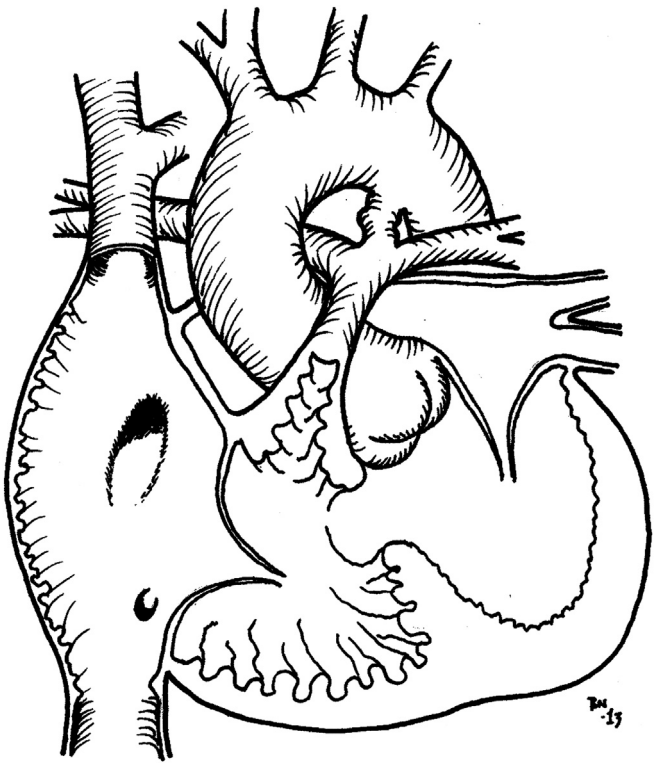

Fig. 7. Pulmonary atresia with ventricular septal defect. There is no other blood supply to the lungs in this case than from the aorta through the patent ductus.

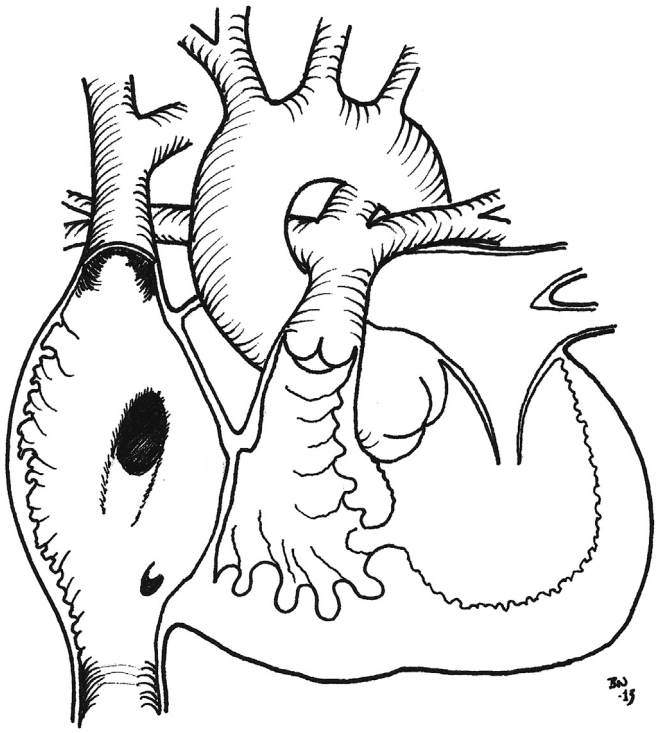

Fig. 8. Tricuspid atresia with a small ventricular septal defect (VSD) and normally related great arteries. Pulmonary blood flow depends on a patent ductus arteriosus because the VSD is so small.

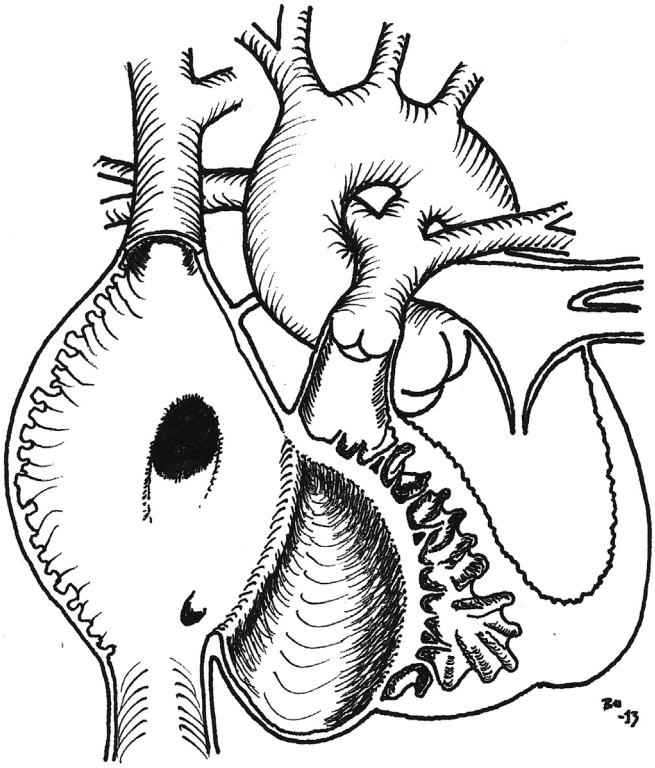

Fig. 9. Ebstein anomaly, i.e. displacement of a dysplastic tricuspid valve into the right ventricle resulting in an 'atrialized' portion of the right ventricle. Pulmonary blood flow depends on a patent ductus because of poor or no forward flow through the pulmonary valve secondary to a large tricuspid regurgitation.

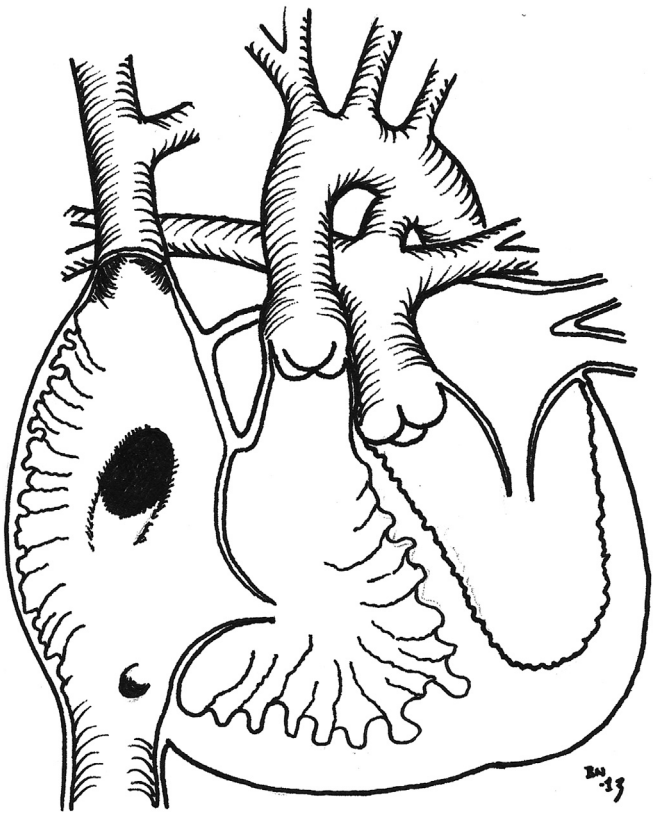

Fig. 10. Transposition of the great arteries. There is possibility for mixing at the atrial and ductal levels.

parallel with decreasing pulmonary vascular resistance, forward flow may increase across the pulmonary valve if the 'atresia' is functional. Nevertheless a surgical systemic-to-pulmonary artery shunt is often necessary initially although it was recently reported that the 15-year survival after complete repair in critically ill neonates was 74%.[39]

8.6. *Transposition of the great arteries (Fig. 10)*

When TGA has been diagnosed and the baby is on prostaglandins the level of the arterial oxygen saturation determines whether a Rashkind septostomy is necessary. The arterial switch operation is usually performed within 1–2 weeks of birth and a septostomy is not necessary if arterial saturations are acceptable and stable (>70%) on treatment with prostaglandin. It has been reported that infants undergoing a Rashkind procedure for TGA have an increased risk of preoperative stroke[40] but this association has subsequently been questioned.[41] Long-term survival (25 years) after the arterial switch procedure exceeded 95% in a recent report.[42]

8.7. *Total anomalous pulmonary venous return with obstruction to pulmonary flow (Fig. 11)*

Total anomalous pulmonary venous return is life-threatening to the newborn only if there is obstruction to pulmonary venous return. This occurs most frequently in the infradiaphragmatic type, when obstruction is almost invariably present. The pulmonary venous blood then passes through a vertical vein down through the diaphragm and usually enters the portal vein system. The obstruction is at this entry site. If severe, the baby will have pronounced desaturation from birth with respiratory distress because of pulmonary edema. This is the only cardiac defect with this

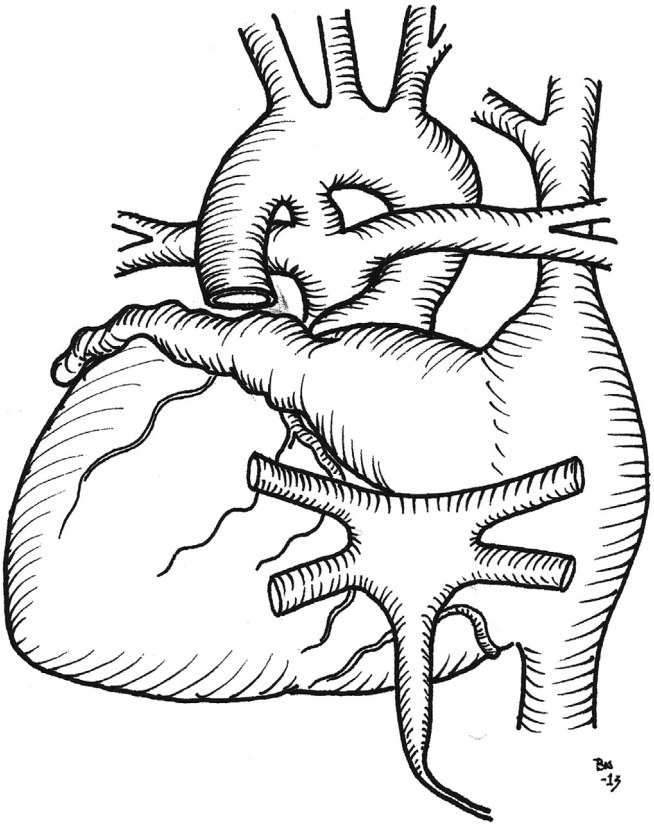

Fig. 11. Total anomalous pulmonary venous return with a pulmonary venous confluence behind the left atrium and a vertical vein descending through the diaphragm. Dorsal view.

clinical picture. The chest X-ray is rather typical with nodular pulmonary edema similar in appearance to meconium aspiration. Therefore a high index of suspicion is required for early diagnosis. Management after diagnosis is emergency open heart surgery. Prostaglandins are of no help in this situation. The 3-year survival after surgery was around 80% in a recent report.[43]

9. Conclusions

The survival after surgery for congenital heart malformations has improved substantially and the long-term prognosis is also good for most of the cardiac defects that are life-threatening to the neonate, such as aortic arch obstruction and TGA. This makes it even more important to ensure that newborn babies with such defects are diagnosed in time before circulatory collapse occurs. The way to achieve this is a combined approach with improvement of both prenatal detection rates and postnatal screening routines. The rate of missed diagnoses of life-threatening cardiac defects in the neonate is an important indicator of quality of care that should be monitored continuously.

Conflict of interest

None.

Funding sources

This work was supported by the Swedish Heart-Lung Foundation.

Practice points

- Life-threatening cardiac malformations are frequently not detected by routine physical examination of the newborn.
- The risk of a missed diagnosis is greatest in aortic arch obstruction but is also significant in TGA, for example.
- Neonatal pulse oximetry screening greatly improves detection rate but often fails to detect aortic arch obstruction.

Research directions

- Improve prenatal screening for duct-dependent cardiac malformations including CoA and TGA.
- Improve neonatal screening for cardiac malformations including methods to detect CoA in the newborn before discharge.

Acknowledgements

The author thanks pediatric cardiac surgeon Boris Nilsson, Queen Silvia Children's Hospital, Göteborg, Sweden for providing the illustrations.

References

1. Carlgren LE, Ericson A, Kallen B. Monitoring of congenital cardiac defects. *Pediatr Cardiol* 1987;**8**:247–56.
2. Hoffman JI, Kaplan S. The incidence of congenital heart disease. *J Am Coll Cardiol* 2002;**39**:1890–900.
3. Pradat P, Francannet C, Harris JA, Robert E. The epidemiology of cardiovascular defects, part I: a study based on data from three large registries of congenital malformations. *Pediatr Cardiol* 2003;**24**:195–221.
4. Abu-Harb M, Hey E, Wren C. Death in infancy from unrecognised congenital heart disease. *Arch Dis Child* 1994;**71**:3–7.
5. Abu-Harb M, Wyllie J, Hey E, Richmond S, Wren C. Presentation of obstructive left heart malformations in infancy. *Arch Dis Child Fetal Neonatal Ed* 1994;**71**: F179–83.
6. Wren C, Richmond S, Donaldson L. Presentation of congenital heart disease in infancy: implications for routine examination. *Arch Dis Child Fetal Neonatal Ed* 1999;**80**:F49–53.
7. Mellander M, Sunnegårdh J. Failure to diagnose critical heart malformations in newborns before discharge – an increasing problem? *Acta Paediatr* 2006;**95**: 407–13.
8. Wren C, Reinhardt Z, Khawaja K. Twenty-year trends in diagnosis of life-threatening neonatal cardiovascular malformations. *Arch Dis Child Fetal Neonatal Ed* 2008;**93**:F33–5.
9. de-Wahl Granelli A, Wennergren M, Sandberg K, et al. Impact of pulse-oximetry screening on the detection of duct-dependent congenital heart disease: a Swedish prospective screening study in 39 899 newborns. *BMJ* 2009;8;**338**:a3037. http://dx.doi.org/10.1136/bmj.a3037.
10. Kuehl KS, Loffredo CA, Ferencz C. Failure to diagnose congenital heart disease in infancy. *Pediatrics* 1999;**103**:743–7.
11. Ainsworth S, Wyllie JP, Wren C. Prevalence and clinical significance of cardiac murmurs in neonates. *Arch Dis Child Fetal Neonatal Ed* 1999;**80**: F43–5.
12. Shultz AH, Localio AR, Clark BJ, Ravishankar C, Videon N, Kimmel SE. Epidemiological features of the presentation of critical congenital heart disease: implications for screening. *Pediatrics* 2008;**121**:751–7.
13. Meberg A, Brugmann-Pieper S, Due R, et al. First day of life pulse oximetry screening to detect congenital heart defects. *J Pediatr* 2008;**152**:761–5.
14. Meberg A, Andreassen A, Brunvand L, et al. Pulse oximetry screening as a complementary strategy to detect critical congenital heart defects. *Acta Paediatr* 2009;**98**:682–6.
15. Riede FT, Wörner C, Dähnert I, Möckel A, Kostelka M, Schneider P. Effectiveness of neonatal pulse oximetry screening for detection of critical congenital heart disease in daily clinical routine: results from a prospective multicenter study. *Eur J Pediatr* 2010;**169**:975–81.
16. Ewer AK, Middleton LJ, Furmston AT, et al. Pulse oximetry screening for congenital heart defects in newborn infants (PulseOx): a test accuracy study. *Lancet* 2011;**378**:785–94.
17. Prudhoe S, Abu-Harb M, Richmond S, Wren C. Neonatal screening for critical cardiovascular anomalies using pulse oximetry. *Arch Dis Child Fetal Neonatal Ed* 2013 Jan 22. http://dx.doi.org/10.1136/archdischild-2012-302045. [Epub ahead of print].
18. Chew C, Halliday JL, Riley MM, Penny DJ. Population-based study of antenatal detection of congenital heart disease by ultrasound examination. *Ultrasound Obstet Gynecol* 2007;**29**:619–24.
19. Granelli AD, Ostman-Smith I. Noninvasive peripheral perfusion index as a possible tool for screening for critical left heart obstruction. *Acta Paediatr* 2007;**96**:1455–9.
20. Calderon J, Angeard N, Moutier S, Plumet M-H, Jambaque I, Bonnet D. Impact of prenatal diagnosis on neurocognitive outcomes in children with transposition of the great arteries. *J Pediatr* 2012;**161**:94–8.
21. Bonnet D, Coltri A, Butera G, et al. Detection of transposition of the great arteries in fetuses reduces neonatal morbidity and mortality. *Circulation* 1999;**99**: 916–8.
22. Mahle WT, Martin GR, Beekman III RH, Morrow WR. Endorsement of Health and Human Services recommendation for pulse oximetry screening for critical congenital heart disease. *Pediatrics* 2012;**129**:190–2.
23. Frank LH, Bradshaw E, Beekman R, Mahle WT, Martin GR. Critical congenital heart disease screening using pulse oximetry. *J Pediatr* 2013; **162**:445–53.
24. Punn R, Silverman NH. Fetal predictors of urgent balloon atrial septostomy in neonates with complete transposition. *J Am Soc Echocardiogr* 2011;**24**: 425–30.
25. Seale AN, Carvalho JS, Gardiner HM, et al. Total anomalous pulmonary venous connection: impact of prenatal diagnosis. *Ultrasound Obstet Gynecol* 2012;**40**: 310–8.
26. Wright GE, Nowak CA, Goldberg CS, Ohye RG, Bove EL, Rocchini AP. Extended resection and end-to-end anastomosis for aortic coarctation in infants: results of a tailored surgical approach. *Ann Thorac Surg* 2005;**80**: 1453–9.
27. Canniffe C, Ou P, Walsh K, Bonnet D, Celermajer D. Hypertension after repair of aortic coarctation – a systematic review. *Int J Cardiol*. http://dx.doi.org/10.1016/j.ijcard.2012.09.08; 2012 Oct 4 [Epub ahead of print].
28. Hraška V, Sinzobahamvya N, Haun C, et al. The long-term outcome of open valvotomy for critical aortic stenosis in neonates. *Ann Thorac Surg* 2012;**94**: 1519–26.
29. Akintürk H, Michel-Behnke I, Valeske K, et al. Hybrid transcatheter–surgical palliation: basis for univentricular or biventricular repair: the Giessen experience. *Pediatr Cardiol* 2007;**28**:79–87.
30. Galantowicz M, Cheatham JP, Phillips A, et al. Hybrid approach for hypoplastic left heart syndrome: intermediate results after the learning curve. *Ann Thorac Surg* 2008;**85**:2063–70.

31. Baba K, Kotani Y, Chetan D, et al. Hybrid versus Norwood strategies for single-ventricle palliation. *Circulation* 2012;**126**:S123–31.
32. Feinstein JA, Benson DW, Dubin AM, et al. Hypoplastic left heart syndrome: current considerations and expectations. *J Am Coll Cardiol* 2012; **59**:S1–42.
33. Idorn L, Olsen M, Jensen AS, et al. Univentricular hearts in Denmark 1977 to 2009: incidence and survival. *Int J Cardiol* 2012 Apr 20. http://dx.doi.org/10.1016/j.ijcard.2012.03.182. [Epub ahead of print].
34. Ekman-Joelsson BM, Sunnegårdh J, Hanseus K, et al. The outcome of children born with pulmonary atresia and intact ventricular septum in Sweden from 1980 to 1999. *Scand Cardiovasc J* 2001;**35**:192–8.
35. Liaáva M, Brooks P, Konstantinov I, Brizard C, d'Udekem Y. Changing trends in the management of pulmonary atresia with intact ventricular septum: the Melbourne experience. *Eur J Cardiothorac Surg* 2011;**40**:1406–11.
36. Hirsch JC, Mosca RS, Bove EL. Complete repair of tetralogy of Fallot in the neonate. Results in the modern era. *Ann Surg* 2000;**232**:508–14.
37. Kanter KR, Kogon BE, Kirshbom PM, Carlock PR. Symptomatic neonatal tetralogy of Fallot: repair or shunt? *Ann Thorac Surg* 2010;**89**:858–63.
38. d'Udekem, Xu MY, Galati JC, et al. Predictors of survival after single-ventricle palliation. The impact of right ventricular dominance. *J Am Coll Cardiol* 2012;**59**: 1178–85.
39. Boston US, Goldberg SP, Ward KE, et al. Complete repair of Ebstein anomaly in neonates and young infants: a 16-year follow-up. *J Thorac Cardiovasc Surg* 2011;**141**:1163–9.
40. McQuillen PS, Hamrick EG, Perez MJ, et al. Balloon atrial septostomy is associated with preoperative stroke in neonates with transposition of the great arteries. *Circulation* 2006;**113**:280–5.
41. Polito A, Ricci Z, Fragasso T, Cogo PE. Balloon atrial septostomy and preoperative brain injury in neonates with transposition of the great arteries: a systematic review and a meta-analysis. *Cardiol Young* 2012;**22**:1–7.
42. Khairy P, Clair M, Fernandes SM, et al. Cardiovascular outcomes following the arterial switch operation for d-transposition of the great arteries. *Circulation* 2013;**127**:331–9.
43. Seale AN, Uemura H, Webber SA, et al. Total anomalous pulmonary venous connection. Morphology and outcome from an international population-based study. *Circulation* 2010;**122**:2718–26.