(7) Discussion

Previous studies have shown that atrial function is particularly important when ventricular dysfunction exists [8-11]. In patients with congenital heart disease, the right ventricular function is frequently reduced due to volume and/or pressure overloading. Tissue Doppler derived strain rate is a promising parameter to quantify regional myocardial function. To our knowledge the present study is the first report on evaluation of the right atrial function in patients with congenital heart disease using echocardiography and tissue Doppler imaging. Our results show that right atrial pump function is unchanged under right ventricular volume over-loading before ASD closure and is reduced after surgical closure but preserved after interventional occlusion. In patients following corrective surgery of TOF the right atrial pump function is impaired in comparison to that of controls. However right atrial pump function may be relatively enhanced in this group of patients when right ventricular dysfunction exists.

7.1 Atrial strain rate curve derived from tissue Doppler imaging

The tissue Doppler imaging derived strain rate is mainly used to evaluate regional ventricular myocardial function and has already been validated as a reliable method providing quantitative information on myocardial contractile function [37-39, 44, 49, 50]. The present study shows that right atrial performance can also be evaluated by tissue Doppler imaging.

Strain rate measurement in the atrium is limited by its thin wall. To overcome this we use a pixel size of 1∗1 and a computation distance of 2-3 mm for longitudinal strain rate calculation. Although using small pixels may theoretically lead to a "noisy" strain rate curve, we still find it possible to identify the atrial strain rate curve peaks when acquisition is performed with an optimal 2-D gain and a frame rate of 110-150 per second is achieved.

The atrial strain rate curve is characterized by the three main waves S, E and A, which coincided with the ventricular systolic, early diastolic and late diastolic periods respectively. It is interesting that the direction of the atrial strain rate curve was just the opposite to that of the ventricular strain rate curve (figure 6). A negative strain rate means that the tissue segment is becoming shorter (or thinner), whereas a positive strain rate means that the segment is becoming longer (or thicker). Thus the negative atrial strain rate late diastolic peak, which occurs in the late diastole, may well reflect the regional atrial pump function. Our findings support previous studies that explain the mechanism of tissue Doppler imaging derived myocardial strain and the atrial movements [9, 20, 25-28, 56-59]

7.2 Right atrial pump function in patients before ASD closure

Similar to ventricular systolic function, atrial pump function is also influenced by preload, afterload and myocardial contractility. It is well established that atrial pump function is inversely related to the afterload and that worsened atrial myocardial contractility may

also lead to reduced atrial pump function [1, 60]. Wang et al. found in an animal trial that left atrial pump function was augmented by volume loading [61], but the method they applied to measure left atrial function was M-mode echocardiography, which may be less reliable in determining left atrial size.

In the present study, right atrial pump function is evaluated through the 2-D echocardiographic area method and tissue Doppler imaging. Compared to normal subjects the ASD patients had significantly higher right atrial area at onset of atrial contraction, which indicates a higher preload for the right atrium. Nevertheless, there were no significant differences in right atrial emptying area fraction or regional peak late diastolic strain rate (A_{SR}) between the normal controls and ASD patients. This indicates that the right heart volume overloading in ASD patients has little influence on the right atrial pump function, although the right atrial active pump volume and its absolute devotion to the ventricular filling may increase with the preload, since the right atrial active emptying area correlates significantly to the Qp/Qs and the right atrial area at onset of atrial contraction.

7.3 Effects of surgical and catheter closure on global right atrial pump function

Right ventricular function in ASD patients, both systolic and diastolic, is reported to be impaired by cardiopulmonary bypass but preserved after device closure [62-68]. The right ventricle is particularly susceptible to the problems of cardiopulmonary bypass and intraoperative ischemia because it is composed largely of longitudinal muscle fibres,

distribution of cardioplegic solution is rarely uniform and the myocardial temperature is higher due to the exposed position of the right ventricle in the mediastinum during surgery [65, 66, 69-72].

Our results show that right atrial global pump function, reflected by the active emptying area fraction, is also significantly reduced after surgical closure but preserved after catheter ASD closure. Surgical incision, diminished ventricular compliance, and hypothermia as well as myocardial damage secondary to cardiopulmonary bypass may all contribute to the change in right atrial function after surgery [1].

7.4 The value of tissue Doppler imaging on the evaluation of right atrial pump function in patients before and after surgical or catheter ASD closure

One of the advantages of tissue Doppler imaging is that it can provide information on regional myocardial function which may be important for the comprehensive understanding of cardiac performance. Our data show that after surgical ASD closure the right atrial lateral wall late diastolic strain rate peak (A_{SR}) was significantly reduced while the performance of the atrial septum remained unchanged. We suggest that the surgical incision and the resultant scars in the right atrial free lateral wall may be the main reason for the acute reduction of right atrial pump function after surgical ASD closure. This explanation is confirmed by the absence of such changes in atrial function after interventional closure of ASD by means of an ASO device.

7.5 Global right atrial pump function in patients with corrected TOF

Right ventricular dysfunction secondary to pulmonary regurgitation or residual right ventricular outflow tract obstruction is frequently observed in the long-term follow-up of patients after corrective surgery of tetralogy of Fallot [18, 73-76]. Recent studies in adults have demonstrated that left atrial function is a crucial determinant of ventricular filling in patients with impaired left ventricular relaxation [1, 8] and the left atrium plays an important role during the course of evolving heart failure [77, 78]. However, information about right atrial function in corrected TOF patients is sparse. In the present study the right atrial pump function, expressed as active empting area fraction, is reduced in postoperative TOF patients. This can be explained by the preoperative hypoxic and surgical right atrial myocardial damage in TOF patients [79-81]. Furthermore, we found that right atrial active/passive empting area ratio in TOF patients was significantly higher than in normal subjects. This may indicate that the right atrium has to pump more to achieve ventricular filling due to the abnormal right ventricular relaxation in this group of patients [74, 82-86].

7.6 Regional right atrial performance in patients with corrected TOF

As well as the global situation in right ventricle, regional right ventricular deformation assessed by tissue Doppler imaging is reduced in patients following corrective surgery of tetralogy of Fallot [87, 88]. Our data show that this also occurs in the right atium. The

reduced right atrial strain rate systolic and early diastolic peaks may reflect the decreased right ventricular function and increased atrial stiffness since the right atrium has no active motion in the ventricular systolic and early diastolic periods. In contrast, the reduced right atrial stain rate late diastolic peak may indicate the reduced atrial pump function. This finding is consistent with the results of 2-D echocardiography.

7.7 Relation between right atrial pump function and right ventricular systolic function in patients following corrective surgery of TOF

In the present study TOF patients with reduced systolic function (EF less than 50 %) had a relatively higher right atrial late diastolic strain rate peak, indicating increased atrial pump function. This may be an adaptive compensatory mechanism of the right atrium to prevent further deterioration of haemodynamics arising from right ventricular dysfunction, although such compensation is incomplete. A similar compensatory mechanism of the left atrium has been reported in patients with left ventricular dysfunction [1, 8]. We did not find a significant difference in the right atrial active emptying fraction, which serves as a global parameter, when comparing right ventricular ejection fraction in the normal and study groups. Changes in the regional myocardial function may occur before any global alteration is apparent, and could explain our findings.

Right ventricular restrictive physiology as indicated by Doppler detectable antegrade forward flow in the pulmonary artery in late diastole is an important phenomenon after

repair of tetralogy of Fallot [54, 55]. Only five of our patients had restrictive right ventricular physiology, which makes statistical comparison of atrial function between the restrictive and non-restrictive groups impossible. However, since atrial performance is inversely influenced by its afterload, we assume that right atrial pump function is reduced when facing a restrictive right ventricle. In this situation the compensating mechanism between right atrium and right ventricle could be hampered. Further studies addressing this point are needed to confirm this assumption.