Ventricular Septal Dysfunction After Surgical Closure of Multiple Ventricular Septal Defects

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Background. **We assessed the global and regional ventricular septal functions using conventional echocardiography and two-dimensional speckle tracking imaging in children with postoperative multiple ventricular septal defects.**

Methods. **Thirty-six children were studied: 16 with postoperative multiple ventricular septal defects and 20 normal control subjects. In children with multiple ventricular septal defects, 60 ventricular septal defects were closed using one of three different techniques (patch closure, the sandwich technique, direct closure). Speckle tracking imaging was applied to three short-axis echocardiographic images.**

Results. **The total patch area used in the multiple ventricular septal defects group was correlated with the postoperative ejection fraction ($r = 0.703$) and Tei index ($r = 0.778$). The global septal peak systolic radial displacement and global septal peak systolic radial strain in the multiple ventricular septal defects group were significantly lower than those observed in the control subjects. The peak systolic radial strain in the segments closed with patches and the peak systolic radial displacement in the segments closed with the felt sandwich technique were significantly lower than those observed in the intact septal segments. No significant regional functional depressions were identified in the segments that were closed directly.**

Conclusions. **The postoperative ventricular global and septal functions were significantly reduced in children with multiple ventricular septal defects, especially in the cases with complex congenital heart disease and that were closed with large prosthetic materials. These results suggest that an effort to minimize the use of patch materials may lead to preserved postoperative ventricular function.**

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The surgical management of multiple ventricular septal defects (mVSDs) remains controversial and challenging [1–3]. The ideal goal of the treatment for mVSDs is complete obliteration without ventricular dysfunction. A novel technique has been introduced for the closure of muscular VSDs, which is performed by sandwiching the septum between two felt patches placed in the left and right ventricles (the felt sandwich technique) [4–6]. This technique requires neither ventriculotomy nor transection of muscular trabeculations. Although the felt sandwich technique improves the outcomes of surgical management of patients with mVSDs [4], postoperative cardiac dysfunction caused by the use of numerous felt patches has been reported [5]. Currently, we also use the transatrial reendocardialization (TAR) technique reported by Alsoufi and colleagues to minimize the number of patches and the incidence of postoperative cardiac dysfunction [7].

Recently, echocardiography-based two-dimensional speckle tracking imaging (2DSTI) has become a validated technique that allows for the quantitative analysis of myocardial wall motion and deformation [8]. We investigated the regional ventricular septal function and its relation to closure techniques using 2DSTI in children who underwent closure of mVSDs.

Patients and Methods

Patient Population

The study design was approved by the institutional review board of the University of Toyama. Written informed consent was obtained from the parents of all patients. Thirty-six children younger than 7 years were included in this study: 16 children with mVSDs who had undergone biventricular repair and 20 normal controls who were healthy children with structurally and functionally normal echocardiograms were investigated for innocent murmurs or screening purposes. Eight of the 16 patients with mVSDs had associated cardiac anomalies, including double-outlet right ventricle in four cases, tetralogy of Fallot in three cases, and coarctation of the aorta in one case. In the mVSDs group, the median age at operation was 8.0 months (range, 3 to 29 months) and the median

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Abbreviations and Acronyms

2DSTI	= two-dimensional speckle tracking imaging
BSA	= body surface area
E/A	= ratio between the early and late diastolic transmitral flow velocity
LV	= left ventricular
LVDd	= left ventricular end-diastolic diameter
LVEF	= left ventricular ejection fraction
mVSDs	= multiple ventricular septal defects
PSCS	= peak systolic circumferential strain
PSRD	= peak systolic radial displacement
%PSRD	= percent peak systolic radial displacement
PSRS	= peak systolic radial strain
RBBB	= right bundle branch block
TAR	= transatrial reendocardialization
VSD	= ventricular septal defect

weight was 6.6 kg (range, 4.9 to 12.1 kg). Sixty VSDs were closed using three different techniques (patch closure: 17, sandwich technique: 7, direct closure: 36). The location and closure techniques of the mVSDs are shown in Figure 1.

Surgical Strategy and Technique for Muscular VSDs

Our current procedures for muscular VSDs have been described previously [4–6]. Each operation was performed with cardiopulmonary bypass. After cardioplegic arrest, a longitudinal right atriotomy was made to access the VSDs. The perimembranous VSDs were closed with a Dacron polyester fabric patch (Boston Scientific, Wayne, NJ). Initially, an attempt was made to close the muscular VSDs with two layers of endocardial running sutures using 6-0 polypropylene sutures [7]. The felt sandwich technique was indicated primarily for large apical or midtrabecular VSDs [6]. The details of the felt sandwich technique have been described in previous reports. A 3-Fr Nelaton catheter (Bard, Haverhill, MA), secured to a 4-0 braided polyester suture mounted onto an oversized (2–4 mm larger than the estimated size of the VSD) circular polyester felt patch, was grasped by right-angled forceps and pulled back into the right ventricle. The suture ends were then passed through a slightly smaller polyester felt patch. The suture was then tied, thus sandwiching the septum between the two polyester felt patches. The location and size of the defects and the closure techniques were precisely reported in the operative records according to the classification of Serraf and associates [1].

We hypothesized that the larger area of VSD patches might cause postoperative ventricular septal dysfunction. The total patch area to body surface area (BSA) ratio was calculated based on the following equation: Total VSD patch area/BSA = the sum of all VSD patch area (cm^2)/BSA at repair (m^2), as previously described [5].

Echocardiographic Analysis

More than 3 months after the operation, echocardiography was performed using a Vivid 7 echocardiographic system (GE Medical Systems, Wauwatosa, WI) with probe frequencies appropriate for the patient size. The left ventricular ejection fraction (LVEF) was determined according to the modified biplane Simpson's method. The left ventricular end-diastolic diameter (LVDd) was also normalized to the patient's BSA and converted to Z-score based on normal subject measurements [9]. Pulse-wave Doppler was used to measure the ratio between the early and late diastolic transmitral flow velocity (E/A). The Tei index was calculated as the sum of isovolumic contraction time and the isovolumic relaxation time divided by the ejection time, as described previously [10]. For the radial speckle tracking analysis, two-dimensional short axis images of the left ventricle were acquired at the three levels as follows: the basal level (the mitral valve), the midventricular level (the prominent papillary muscles), and the apical level (the left ventricular [LV] cavity alone with no visible papillary muscles).

The images were analyzed offline on an EchoPAC workstation (GE Medical Systems, Wauwatosa, WI). The endocardial border of each short-axis plane was traced manually. A second larger outer circle was then generated by the computer algorithm, which was manually adjusted to cover the LV myocardium. Then, the software algorithm automatically segmented the LV short-axis plane into six equidistant segments and searched speckles in the region of interest on a frame-by-frame basis using the sum of the absolute difference algorithm. Two (anteroseptum and septum) of the six segments were septal regions (Figure 2). Deformation was assessed according to the peak systolic radial strain (PSRS: percent change in segment thickness during systole, %), peak systolic circumferential strain (PSCS: percent change in segment circumferential length during systole, %), and peak systolic radial displacement (PSRD: myocardial displacement toward the contractile center during systole, mm). To account for changes in heart size, the PSRD was divided by the LVDd (mm) and defined as the percent PSRD (%PSRD, %). The circumferential strain measurements were represented by negative curves. We defined the sum of the PSRS of the six septal segments as the "global septal PSRS," the sum of the PSCS values of the six septal segments as the "global septal PSCS," and the sum of the %PSRD of the six septal segments as the "global septal %PSRD".

To assess the influence of the closure technique on the regional ventricular septal function, each septal segment was subdivided into four groups (patch closure, felt sandwich closure, direct closure, intact area) by identifying the patches on echocardiography or referring to the operative records.

Statistical Analysis

Continuous variables were expressed as the mean ± standard deviation. The data were analyzed using the JMP 9 software program (SAS Institute Inc, Cary, NC). Comparisons of continuous variables between two groups were made using unpaired Student's *t* test or the Wilcoxon rank-sum test as appropriate. Comparisons among more than three groups were made using a one-way analysis of variance (ANOVA) with a post hoc