Multimodality imaging and three-dimensional printed model in patients with left ventricular outflow tract obstruction

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Abstract

Surgical treatment is an effective therapy and the gold standard for patients with left ventricular outflow tract obstruction (LVOTO) and drug-refractory symptoms. However, it is difficult to arrange a concrete surgical plan due to the heterogenous and complex cardiac anatomy. Three-dimensional (3D) printing is an emerging technology that is able to reproduce complex cardiac anatomy. Here, we present two patients with LVOTO in whom we created 3D printed models. In these two patients, we compared the 3D printed model and the intraoperative findings and confirmed that the 3D printed model we created could reproduce the complex cardiac anatomy including the interventricular septum, papillary muscles, and abnormally thickened chordae. By using 3D printed models, cardiologists and surgeons can comprehend the complex 3D cardiac structure and spatial positional relationship preoperatively and perform surgical rehearsal. 3D printing could be a valuable tool for the management of patients with LVOTO.

Keywords Left ventricular outflow tract obstruction; Multimodality imaging; Three-dimensional printing; Surgery

Introduction

Left ventricular outflow tract obstruction (LVOTO) is associated with debilitating symptoms and a poor prognosis.1 Surgical treatment is an effective therapy and the gold standard for patients with LVOTO and drug-refractory symptoms.2,3 However, it is difficult to select and make a concrete surgical plan due to the heterogenous and complex cardiac anatomy.

Multimodality imaging such as echocardiography and/or computed tomography (CT) is a promising tool for the evaluation of patients with LVOTO. In addition, three-dimensional (3D) printing is an emerging technology that is able to reproduce complex cardiac anatomy.4 In the field of pediatric cardiology, 3D printed models are reported to be useful for evaluation and simulation of surgical treatment.5 Here, we present two patients with LVOTO who were evaluated using multimodality imaging and 3D printed models.

Case report

We included two patients with LVOTO in whom surgical treatment was planned at our institution. Signed informed consent to create a 3D printed model and to use their medical records was obtained from each patient. 3D printing of the heart was performed using contrast-enhanced CT data in the diastolic phase. A stereolithography file of the
myocardial model was generated using the software Mimics (Materialize, Leuven, Belgium) and exported to a 3D printer system (RM-6000 II, CMET; Yokohama, Japan). Baseline characteristics of the two patients are summarized in Table 1.

Case 1

A 73-year-old woman with hypertrophic obstructive cardiomyopathy was referred to our institution for further management of severe dyspnoea. Transthoracic echocardiography showed a symmetrically hypertrophied left ventricle with maximum thickness of 17 mm (Figure 1A). Peak pressure gradient at the LVOT was 144 mmHg at rest. We performed transesophageal echocardiography and contrast-enhanced CT for further evaluation of the LVOTO and revealed that both the anterior and posterior papillary muscles were significantly hypertrophied and the anterior papillary muscle was directly inserted into the mitral valve generating the LVOTO (Figure 1B and C). At the heart team conference at our institution, it was decided to perform surgical treatment, and a 3D printed model was created. The 3D printed model could reproduce the hypertrophied papillary muscles and the direct insertion of the anterior papillary muscle into the mitral valve. By creating a 3D printed model, we could understand the 3D structure of complex cardiac anatomy and spatial relationship between the interventricular septum, mitral valve, and the papillary muscles from the surgeon’s view (Figure 1D and E). The intraoperative findings confirmed the existence of severely hypertrophied papillary muscles as indicated preoperatively by the 3D printed model (Figure 1F).

Case 2

A 57-year-old woman previously diagnosed with drug-refractory symptomatic hypertrophic obstructive cardiomyopathy was referred to our institution. Transthoracic echocardiography showed concentric left ventricular hypertrophy with a maximum wall thickness of 12 mm and a maximum pressure gradient of 73 mmHg across the LVOT at rest. An abnormal structure like thickened chordae was noted in the lateral side of the left ventricle (Figure 2A); however, the precise mechanism of LVOTO was not revealed. Transesophageal echocardiography and contrast-enhanced CT showed that the abnormal funicular structure at the basal septum and abnormally thickened chordae caused LVOTO, suggesting that the patient had sub-aortic stenosis (Figure 2B and C). At the heart team conference, it was decided to perform surgery to alleviate LVOTO due to sub-aortic stenosis, and a 3D printed model was created. The 3D printed model could reproduce the abnormally thickened chordae and sub-aortic stenosis. The 3D printed model enabled us to comprehend the 3D relationship between the abnormally thickened chordae and the mitral valve (Figure 2D) and also enabled us to stereographically recognize the extent of sub-aortic stenosis from the surgeon’s view (Figure 2E). The intraoperative findings confirmed that the patient had sub-aortic stenosis (Figure 2F), and the abnormal funicular structure and abnormally thickened chordae were surgically resected.

Discussion

In this report, we evaluated patients with LVOTO using multimodality imaging and created 3D printed models. We

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Table 1 Characteristics of the patients with left ventricular outflow tract obstruction

| Characteristic                        | Case 1 | Case 2 |
|--------------------------------------|--------|--------|
| **<Backgrounds>**                    |        |        |
| Age (years)                          | 73     | 57     |
| Sex                                  | Female | Female |
| Symptom                              | Dyspnoea | Chest pain |
| NYHA functional class                | III    | II     |
| Medications                          | Bisoprolol 5 mg, cibenzoline 150 mg | Bisoprolol 5 mg, verapamil 120 mg, cibenzoline 150 mg |
| B-type natriuretic peptide (pg/mL)  | 1216   | 35     |
| **<Echocardiography>**               |        |        |
| Left ventricular ejection fraction (%)| 65     | 65     |
| Maximum wall thickness (mm)          | 17     | 12     |
| Peak pressure gradient at rest (mmHg)| 144    | 73     |
| SAM of the mitral valve              | 1+     | 1+     |
| Degree of mitral regurgitation       |        |        |
| Abnormality of cardiac structure     | Hypertrophied papillary muscle directly inserted into the mitral valve | Sub-aortic stenosis and abnormally thickened chordae |

NYHA, New York Heart Association; SAM, systolic anterior motion.
Figure 1  (A) Transthoracic echocardiography (parasternal long-axis view). (B) Transesophageal echocardiography. (C) Contract-enhanced computed tomography. (D, E) The 3D printed model of the patient. View across the mitral valve (D) and across the aortic valve (E). (F) The intraoperative finding across the aortic valve. AML, anterior mitral leaflet; Ao, aorta; AV, aortic valve; LA, left atrium; LCC, left coronary cusp; LV, left ventricle; MV, mitral valve; NCC, non-coronary cusp; PM, papillary muscle; PML, posterior mitral leaflet; RCC, right coronary cusp.

Figure 2  (A) Transthoracic echocardiography (apical five chamber view). (B) Transesophageal echocardiography. Sub-aortic stenosis (blue arrow) was noted. (C) Contract-enhanced computed tomography. Sub-aortic stenosis (blue arrow) and the abnormally thickened chordae (yellow arrow) were noted. (D, E) The 3D printed model of the patient. Yellow arrow showed the thickened chordae and blue arrow showed the sub-aortic stenosis. (F) The intraoperative finding across the aortic valve. Abnormal funicular structure (blue arrow) was confirmed. Ao, aorta; AV, aortic valve; LA, left atrium; LV, left ventricle; MV, mitral valve; RA, right atrium; RV, right ventricle.
found that these modalities could play a certain role in the management of patients with LVOTO.

**Multimodality imaging and three-dimensional printing in patients with left ventricular outflow tract obstruction**

The mechanism of LVOTO is multifactorial and heterogeneous. Abnormality of the mitral subvalvular apparatus and sub-aortic stenosis can cause LVOTO; however, these abnormalities are sometimes missed in daily practice. In this report, both patients underwent transesophageal echocardiography and contrast-enhanced CT for the evaluation of LVOTO. These modalities enabled us to further address the mechanism of LVOTO in both case 1 (with a hypertrophied papillary muscle directly inserted into the mitral valve) and case 2 (with sub-aortic stenosis and abnormally thickened chordae), suggesting the importance of multimodality imaging for the assessment of patients with LVOTO.

On the other hand, it is difficult for cardiologists to fully understand the 3D structure of the complex cardiac anatomy. The 3D printed model we created was constructed on a 1:1 scale with reasonable reproducibility and could be turned over from all views. By using the 3D printed model, we could understand the spatial positional relationship between interventricular septum and mitral subvalvular apparatus such as hypertrophied papillary muscles and thickened chordae as shown in Figures 1 and 2. These complex 3D structures were otherwise difficult to understand. By understanding the 3D cardiac structure using a 3D printed model, cardiologists can feedback and improve the performance of imaging modalities such as echocardiography and CT, perhaps resulting in more effective evaluation of patients with LVOTO.

**Surgical strategy in patients with left ventricular outflow tract obstruction using three-dimensional printed model**

As well as in other cardiovascular fields, 3D printing could be promising for surgical simulation in patients with LVOTO. In this report, we confirmed that 3D printed model could reproduce the interventricular septum, papillary muscles, and abnormally thickened chordae. By using 3D printed models, surgeons can comprehend the complex 3D cardiac structure preoperatively from the surgeon’s view and perform surgical rehearsal. Although surgeon did not perform surgical simulation in these two patients because we would like to compare the intact 3D printed model and intraoperative findings, the use of a 3D printed model for operative rehearsal may have a yield, especially in unusual cases in which surgeons confront extremely abnormal anatomy and for young surgeons with less experience. Meanwhile, particularly thin or small structures are not yet printable. Indeed, our 3D printed model could not reproduce some chordae and muscular bundle. Thus, further improvements of the reproducibility are strongly warranted.

**Conclusions**

In this case series, we evaluated patients with LVOTO using multimodality imaging and 3D printed models. 3D printing could be a valuable tool for the management of patients with LVOTO.

**Conflict of interest**

None declared.

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