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Original article

Assessment of deformation of the mitral valve complex during off-pump coronary artery bypass surgery using three-dimensional echocardiography in a porcine model

Takashi Igarashi (MD, PhD)[a,*], Masumi Iwai-Takano (MD, PhD, FJCC)[b], Hiroki Wakamatsu (MD, PhD)[a], Mineyuki Haruta (PhD)[c], Sadao Omata (PhD)[c], Hitoshi Yokoyama (MD, PhD)[a]

[a] Department of Cardiovascular Surgery, Fukushima Medical University, Fukushima, Japan
[b] Intensive Care Unit, Fukushima Medical University, Fukushima, Japan
[c] Department of Electrical and Electronics Engineering, College of Engineering, Nihon University, Koriyama, Japan

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ABSTRACT

Background: This study aimed to assess the deformation of the mitral valve complex during the displacement of the beating heart by using three-dimensional echocardiography in a porcine off-pump coronary artery bypass grafting (OPCAB) model.
Methods: In nine healthy swine, we positioned the beating heart as an OPCAB model, i.e. control, left anterior descending artery (LAD), right coronary artery (RCA), and left circumflex artery (LCX) positions. In each position, three-dimensional echocardiography was performed to assess the mitral valve complex with hemodynamic parameters. We analyzed the deformation of the mitral valve and the three-dimensional coordinates of the papillary muscles.
Results: There was a significant increase in maximum tenting length and tenting volume (control 0.70 ± 0.30, LAD 0.65 ± 0.27, RCA 0.79 ± 0.23, LCX $0.95 \pm 0.34\ cm^3$, $p < 0.05$) in the LCX position compared with the other positions. The posterior papillary muscle (PPM) angle had a significant relationship with the tenting volume ($r = -0.643$, $p < 0.001$). The PPM was displaced to the medial side in the LAD and LCX positions ($p < 0.01$).
Conclusions: The prime cause of the deformation of the mitral leaflets is suggested to be the displacement of the PPM associated with the change in geometry of the left ventricle in a porcine model.

Introduction

To avoid extracorporeal circulation, manipulation of the aorta, and cardiac arrest, off-pump coronary artery bypass grafting (OPCAB) is a safe, minimally-invasive surgical treatment for high-risk patients [1–4], especially for those with advanced age, low ejection fraction, chronic obstructive pulmonary disease, renal insufficiency, and/or atheromatous disease of the ascending aorta. Recently, OPCAB has been widely performed around the world, accounting for about 65% of all coronary artery bypass grafting (CABG) in Japan and 15–20% in the USA and in countries belonging to the European Union.

During OPCAB, it is important to stabilize the hemodynamics, especially when the surgeon needs both elevation and displacement of the beating heart [5–9]. Several clinical investigations reported that the operative mortality is higher in cases with hemodynamic instability with consequent urgent pump conversion during OPCAB compared to that in cases with conventional on-pump arrested CABG [6,7,9]. Although several predictors for hemodynamic instability during OPCAB have been reported [5,6,8,10], intraoperative worsening of mitral regurgitation (MR) is one of the significant predictors [5,10–12], which is often observed during elevation and displacement of the beating heart.

A few recent investigations have reported deformation of the mitral valve complex related to MR during OPCAB. Koga et al. reported that displacement of the beating heart, combined with occlusion of the left circumflex artery (LCX), causes MR from the posteromedial site of the mitral valve due to enlargement of the posteromedial dimension of the mitral annulus in an OPCAB

* Corresponding author at: Department of Cardiovascular Surgery, Fukushima Medical University, Hikarigaoka 1, Fukushima 960-1295, Japan.
E-mail address: tigarashi5150@gmail.com (T. Igarashi).

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animal model [13]. George et al. reported that the mitral valve is folded and twisted in the displaced position in patients during OPCAB [12]. However, the mechanism of the occurrence and worsening of the MR during displacement of the beating heart in OPCAB remains unclear.

In this study, we hypothesized that deformation of the mitral valve complex, such as the leaflet, annulus, chorda, and papillary muscle, causes occurrence and worsening of the MR during OPCAB in patients with ischemic heart disease. The aim of this study was to assess the deformation of the mitral valve complex during displacement of the heart using three-dimensional echocardiography in a porcine OPCAB model.

Materials and methods

Animal preparation

Female Landrace large white Duroc pigs ($n = 9$; Saitama Experimental Animals Supply Co., Ltd., Saitama, Japan) weighing 50.5 ± 2.5 kg on a cholesterol-free diet were used humanely in compliance with the 'Principles of Laboratory Animal Care' formulated by the National Society for Medical Research and the 'Guide for the Care and Use of Laboratory Animals' prepared by the Institute of Laboratory Animals Resources and published by the National Institute of Health (Publication No. 86-23, revised 1985). This study was approved by the institutional ethics committee of Fukushima Medical University.

After anesthesia with an intramuscular injection of ketamine (20 mg/kg), atropine (1 mg), and pentobarbital sodium (30 mg/kg) into the neck, the pig was placed on an operating table in the supine position. An ear vein was canulated for fluid and drug administration. After tracheotomy and endotracheal intubation, mechanical positive pressure ventilation was maintained with a mixture of oxygen and isoflurane at a tidal volume of 10 mL/kg. Anesthesia was maintained by isoflurane inhalation (0.5%–5%) and a bolus injection of pentobarbital (25 mg/kg) (Fig. 1a).

The external electrocardiogram (lead II) and the blood pressure in the femoral artery were continuously monitored. A Swan-Ganz catheter (Edwards Lifesciences, Irvine, CA, USA) was inserted from the femoral vein into the pulmonary artery, and the pulmonary arterial pressure was continuously monitored (Vigilance II Monitor®, Edwards Lifesciences). The pericardium was left open through a median sternotomy. To maintain good heart exposure, a sternal retractor was used. The width of the retractor was 8 cm.

Similar to clinical OPCAB surgery, the heart was placed in four positions: control, left anterior descending artery (LAD), right coronary artery (RCA), and LCX positions. In the LAD position, a gauze was inserted into the left-side pericardium to displace the apex 2 cm to the right. In the RCA position, the apex was displaced 1 cm ventral and 3 cm superior in the sagittal plane from the control position with an apex suction device (Starfish™; Medtronic, Inc., Minneapolis, MN, USA) for the elevation of the apex [14]. In the LCX position, the apex was displaced 4 cm to the right side in the transverse plane from the RCA position (Fig. 1b). In each

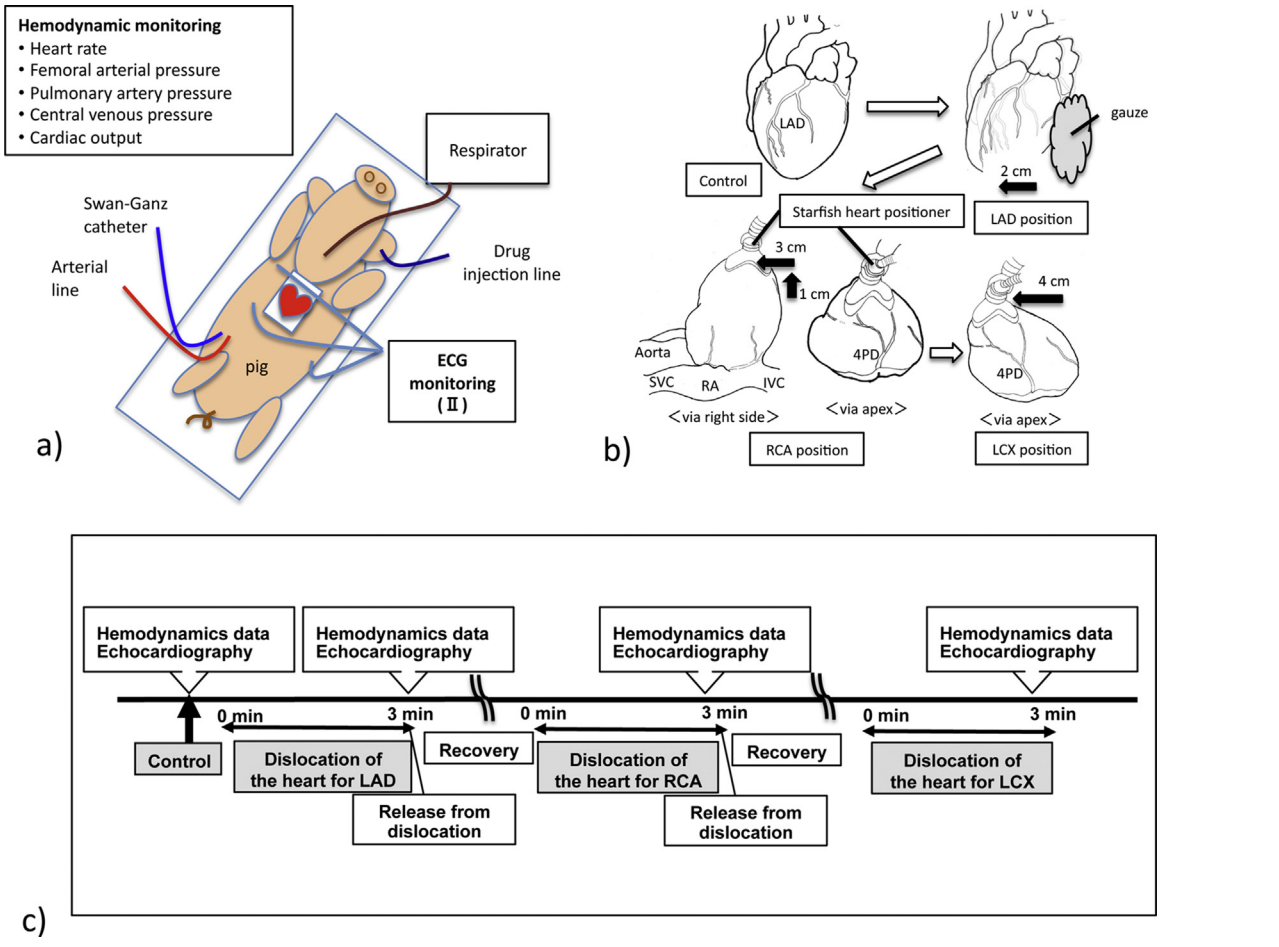

Fig. 1. A schematic overview of the animal preparation, the form of the displacement of the heart and study protocol. (a) A swine was placed in the supine position. Electrocardiogram, respirator, venous injection line, femoral arterial line, and a Swan-Ganz catheter were introduced. (b) The beating heart was positioned in the following four positions in order; the control position, LAD position, RCA position, and LCX position. (c) The echocardiographic and hemodynamic data were acquired in each position. LAD, left anterior descending artery; RCA, right coronary artery; LCX, left circumflex artery.

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