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Sternal Healing after Coronary Artery Bypass Grafting Using Bilateral Internal Thoracic Arteries: Assessment by Computed Tomography Scan

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Background: This study aimed to investigate sternal healing over time and the incidence of poor sternal healing in patients undergoing coronary artery bypass graft (CABG) surgery using bilateral internal thoracic arteries. ***Methods:*** This study enrolled 197 patients who underwent isolated CABG using skeletonized bilateral internal thoracic arteries (sBITA) from 2006 through 2009. Postoperative computed tomography (CT) angiography was performed on all patients at monthly intervals for three to six months after surgery. In 108 patients, an additional CT study was performed 24 to 48 months after surgery. The axial CT images were used to score sternal fusion at the manubrium, the upper sternum, and the lower sternum. These scores were added to evaluate overall healing: a score of 0 to 1 reflected poor healing, a score of 2 to 4 was defined as fair healing, and a score of 5 to 6 indicated complete healing. Medical records were also retrospectively reviewed to identify perioperative variables associated with poor early sternal healing. ***Results:*** Three to six months after surgery, the average total score of sternal healing was 2.07±1.52 and 68 patients (34.5%) showed poor healing. Poor healing was most frequently found in the manubrium, which was scored as zero in 72.6% of patients. In multivariate analysis, the factors associated with poor early healing were shorter post-surgery time, older age, diabetes mellitus, and postoperative renal dysfunction. In later CT images, the average sternal healing score improved to 5.88±0.38 and complete healing was observed in 98.2% of patients. ***Conclusion:*** Complete sternal healing takes more than three months after a median sternotomy for CABG using sBITA. Healing is most delayed in the manubrium.

Key words: 1. Coronary artery bypass
2. Wound healing
3. Mammary arteries
4. Computed tomography

INTRODUCTION

Many reports have investigated sternal wound complications and dehiscence depending on the techniques and devices employed during sternal closure, but sternal healing is usually evaluated by assessing symptoms and through physical examinations [1,2]. Recently, Raman et al. [3] evaluated sternal healing using axial images of chest computed tomography

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(CT) to determine whether sternal reconstruction using rigid fixation with plates results in improved bone healing, and Vestergaard et al. [4] used chest CT to compare sternal healing after the application of either bone wax or Ostene.

In coronary artery bypass grafting (CABG), it has been demonstrated that bilateral internal thoracic artery (BITA) grafting improves survival and reduces the need for additional revascularization, but concerns have been raised about sternal wound infections after BITA grafting [5]. The increased risk of sternal infection after BITA grafting can be minimized by harvesting the internal thoracic arteries in a skeletonized manner with meticulous attention to preserving sternal blood flow, especially in diabetic patients undergoing CABG [6,7]. Skeletonized BITA (sBITA) grafting also results in reduced postoperative pain and dysesthesia and in increased sternal perfusion at follow-up [8]. However, few reports have evaluated sternal healing after CABG using sBITA, which was the focus of our study. Seoul National University Bundang Hospital, we usually have used sBITA for multivessel anastomoses in CABG since 2005, and coronary CT has been regularly performed to evaluate graft patency after CABG. The coronary CT imaging performed in Seoul National University Bundang Hospital included the whole sternum, leading us to hypothesize that coronary CT could allow us to evaluate sternal healing after CABG using sBITA. We reviewed coronary CT records for indications of sternal healing. Our study aimed to investigate the progress of sternal healing over time and the incidence of poor sternal healing in patients undergoing CABG using sBITA.

METHODS

From January 2006 to December 2009, CABG was performed on 526 patients at Seoul National University Bundang Hospital, of whom 340 underwent CABG using sBITA. We included patients who underwent isolated CABG using sBITA and were examined with coronary CT three to six months after the operation. We excluded patients who underwent combined valve surgery, left ventricular remodeling, or aortic surgery, as well as patients who did not undergo coronary CT three to six months after the operation. A total of 197 patients were analyzed, of whom 98 (49.7%) had diabetes mellitus and eight (4.1%) had chronic renal failure. The mean age of the patients was 64.4 years. Off-pump CABG was performed in 143 patients. We used sBITA and closed the sternum with transsternal wiring, using eight to 10 stainless steel wires (thickness number 5.0; Ethicon, Johnson and Johnson Medical GmbH, Norderstedt, Germany) in all patients. Bone wax was used for hemostasis.

The hospital institutional review board approved this study (B-1310/222-105) and individual patient consent was waived. We reviewed the coronary CTs of each of the 197 patients to evaluate early postoperative sternal healing. The coronary CTs of 108 patients who were reexamined 24 to 48 months after the operation were analyzed to evaluate longer-term sternal healing. The coronary CT angiography was performed with a 64-slice MDCT scanner (Brilliance 64; Philips Medical Systems, Best, the Netherlands). Scanning was performed with 64×0.625 mm section collimation, 420 ms rotation time, 120 kV tube voltage, 800 mA tube current, and electrocardiogram-gated dose modulation. A bolus of 80 mL iomeprol (Iomeron 400; Bracco Diagnostics, Milan, Italy) was intravenously injected (4 mL/sec) followed by a 50 mL saline chaser.

Sternal healing was evaluated by an experienced radiologist. The window width was adjusted to 2,000 Hounsfield units, and the window level to 250 Hounsfield units. Sternal healing was scored in the axial CT images at the levels of the manubrium, upper sternum, and lower sternum using the following system: 0=definite visible sternal gap, 1=incomplete reunion or visible bone formation, 2=complete reunion. A definite visible sternal gap refers to cases in which there was a visible separation of both the anterior and posterior plates of the sternum in the CT image. Incomplete fusion was defined as fusion of one plate and separation of the other. Visible bone formation refers to cases in which bone formation was present without definite bone remodeling. Complete fusion was defined as the presence of definite bone remodeling in both the anterior and posterior plates (Fig. 1). The scores assigned to the three levels were summed, and overall sternal healing was categorized as poor (total score 0−1), fair (total score 2−4), or complete (total score 5−6). We compared the scores of the manubrium, upper body, and lower body to determine whether sternal healing varied ac-

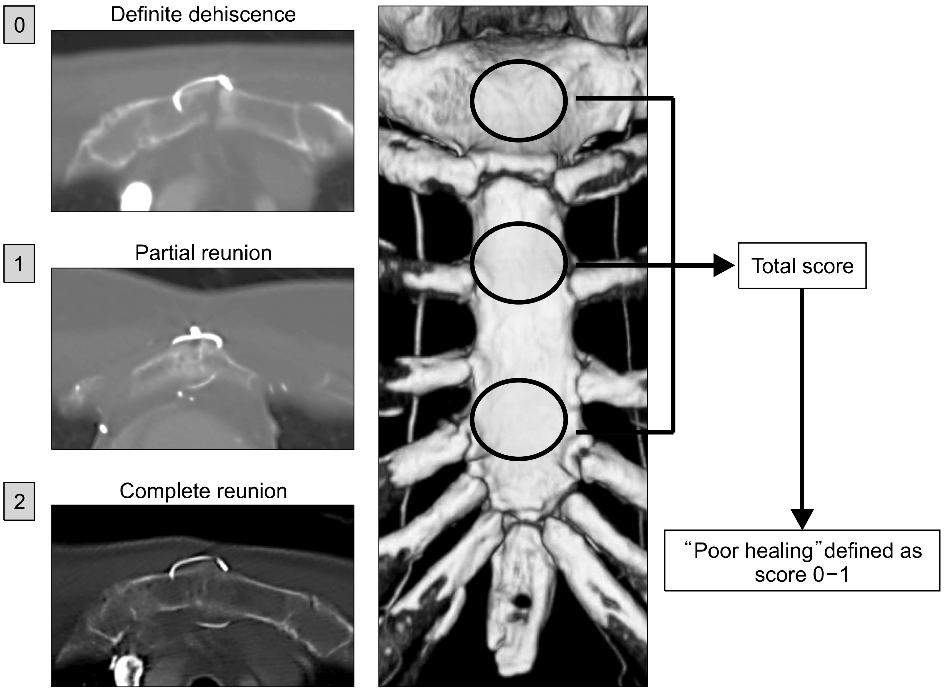

Fig. 1. Scoring of sternal healing.

Table 1. Patient characteristics associated with poor early healing

Variable	Poor early healing (n=68)	Fair early healing (n=129)	p-value (univariate)	p-value (multivariate)
Age (yr)	65.9±8.81	63.6±10.1	0.02	0.028
Gender (male/female)	49/19	93/36	1.0	
Body mass index	24.4±2.5	24.9±2.6	0.026	
Interval (mo)	3.96±0.92	4.74±1.1	0.000	0.000
Diabetes mellitus	44 (65)	54 (42)	0.003	0.03
Smoking history	38 (56)	81 (63)	0.362	
Cardiovascular accident	12 (18)	26 (20)	0.709	
Chronic renal failure	6 (8.8)	2 (1.6)	0.021	0.098
Chronic obstructive pulmonary disease	0	1 (0.8)	1.0	
Peripheral vascular disease	14 (21)	18 (14)	0.231	
Left ventricle dysfunction	14 (21)	12 (9.3)	0.027	0.17
Left main disease	24 (35)	38 (29)	0.423	

Values are presented as mean±standard deviation or number (%).

cording to location. Sternal healing was analyzed and compared at monthly intervals from three to six months after the operation to evaluate the chronological progression of early sternal healing. In order to assess the risk factors for poor early sternal healing, we divided the patients into two groups: a poor early healing group (the P group) and a fair or complete early healing group (the F group). Medical records were also retrospectively reviewed to identify perioperative variables associated with early poor sternal healing, and these variables were compared between the two groups (Tables 1, 2).

Using the same coronary CT scoring techniques, we evaluated the long-term sternal healing of 108 patients who underwent coronary CT 24 to 48 months after the operation. We compared the three locations and the two groups (the P group vs. the F group) to evaluate long-term sternal healing.

All analyses were performed with PASW Statistics for

Table 2. Perioperative variables associated with poor early healing

Variable	Poor early healing (n=68)	Fair early healing (n=129)	p-value (univariate)	p-value (multivariate)
Perioperative intra-aortic balloon pump support	9 (13)	7 (5.4)	0.096	
Emergency operation	6 (8.8)	7 (5.4)	0.377	
Off-pump coronary artery bypass grafting	47 (69.0)	96 (74.0)	0.502	
No. of distal anastomoses	3.85±0.88	3.78±1.1	0.591	
Respiratory complications	2 (2.9)	1 (0.8)	0.274	
Postoperative acute renal failure	5 (7.3)	1 (0.8)	0.019	0.048
Postoperative delirium	5 (7.3)	8 (6.2)	0.769	
Postoperative stroke	0	1 (0.8)	1.0	
Wound dehiscence	9 (13.0)	7 (5.4)	0.096	
Ventilator period (hr)	9.6±9.3	9.5±11	0.940	
Intensive care unit stay (hr)	34.3±24	32.4±23	0.614	

Values are presented as number (%) or mean±standard deviation.

Table 3. Scoring of early and late sternal healing

Score	No. of patient	Manubrium				Upper sternum				Lower sternum				Overall			
		Av.	0	1	2	Av.	0	1	2	Av.	0	1	2	Av.	0–1	2–4	5–6
Early CT	197	0.33	143	43	11	0.88	60	100	37	0.86	60	105	32	2.07	68	116	13
Late CT	108	1.97	1	1	106	1.97	0	6	102	1.94	1	5	102	5.88	0	2	106

Av., average; CT, computed tomography.

Windows ver. 18.0 (SPSS Inc., Chicago, IL, USA). Continuous data were expressed as mean±standard deviation. Categorical data were expressed as percentages. Univariate analysis of categorical data was performed with the chi-square and Fisher's exact tests for categorical variables, and the unpaired t-test or the Mann-Whitney U-test for continuous variables. Multivariate analysis with logistic regression was performed to identify risk factors for poor early sternal healing. p-values less than 0.05 were considered to indicate statistical significance.

RESULTS

1) Early sternal healing

During the period from three to six months after surgery, the average total early sternal healing score was 2.07±1.52. Sixty-eight patients (34.5%) showed poor healing, whereas only 13 patients (6.6%) demonstrated complete healing. Poor healing was more frequently found in the manubrium (average score 0.33, score of zero in 72.6% of patients) than in the upper sternum (average score of 0.88, score of zero in 30.5% of patients) or the lower sternum (average score of 0.86, score of zero in 30.5% of patients) (Table 3). The mean total score continuously increased over time between three and six months after surgery, increasing from 1.3±1.08 at three months after operation to 1.54±1.15 at four months, 1.98±1.18 at five months, and 3.57±1.54 at six months (Fig. 2).

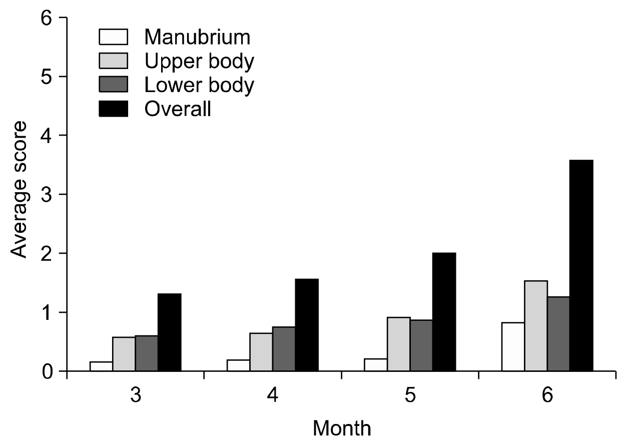

Fig. 2. Sternal healing from three to six months after the operation.

Complete sternal healing was not observed in any patients at three months, in only two patients between four and five months, and in 11 patients at six months after CABG.

Table 1 shows the baseline characteristics of patients with and without poor early sternal healing. Among patients with poor early sternal healing, there was a greater proportion of older age, shorter CT interval from surgery, diabetes mellitus, chronic renal failure, and left ventricular dysfunction. There was no significant difference with respect to sex, body mass index, smoking, cerebrovascular accidents, chronic obstructive pulmonary disease, peripheral vascular disease, or left main disease. The prevalence of perioperative variables is shown in Table 2. Compared to the F group, the P group had more postoperative renal dysfunction. There was no significant difference with respect to the occurrence of emergencies, off-pump coronary artery bypass grafting, number of distal anastomoses, respiratory complications, postoperative delirium, wound dehiscence, postoperative cardiovascular accidents, ventilator duration, or intensive care unit stay hours. According to multivariate analysis, the independent risk factors associated with poor early healing were a shorter interval from surgery, older age, diabetes mellitus, and postoperative renal dysfunction.

2) Long-term sternal healing

In the later CT images, the long-term sternal healing score was 5.88±0.38 and complete healing was observed in 106 patients (98.2%). The score was 1.97±0.21 in the manubrium, 1.94±0.23 in the upper sternum, and 1.94±0.28 in the lower sternum. There was no difference in long-term sternal healing according to location. The average long-term total healing score was 5.78±0.53 in the P group and 5.93±0.26 in the F group. Despite poor early sternal healing, long-term sternal healing did not differ in the two groups and almost all patients showed complete sternal healing (Table 3).

DISCUSSION

In the cases we reviewed, no instances of complete sternal healing were found three months after the operation. At six months, 23.4% of patients (11/47) showed complete sternal healing. Bitkover et al. [9] reported that none of the CT scans they examined showed radiological signs of healing at three months, but that half of the patients had healed completely at six months. They suggested that sternal gaps seen on a CT scan are not necessarily indicative of dehiscence and that minor gaps seen up to six months postoperatively should not be regarded as pathological unless correlated to a clinical instability [9]. In another study, none of 68 patients showed complete radiological sternal healing at three months after the operations [10]. We usually explained to patients that it takes six to eight weeks for the sternum to fuse, but that guidance may not be correct in light of the above studies, including ours. These results suggest that it may take more than three months for radiologically complete sternal healing to take place after an operation regardless of the use of sBITA.

We think that several reasons exist for delayed sternal healing. First, the only cohesive force acting upon the newly fused sternum in the initial postoperative period is the holding power of the sternal sutures, but this is opposed by counterforces such as the action of the respiratory muscles and the negative intrathoracic pressures associated with the volume changes of normal respiration. Vigorous coughing or sneezing can exacerbate these dynamics [11]. These counterforces are thought to cause sternal instability and delay sternal healing. Recently, Pai et al. [12] concluded that rigid plate fixations result in superior sternal stability compared to sternal wiring, and Raman et al. [3] used chest CT to demonstrate that sternal reconstruction using rigid fixation with plates improved bone healing compared to wire cerclage. Second, the increased incidence of sternal complications after internal thoracic artery grafting is believed to result from damaged blood supply to the sternum [13,14] and skeletonization of internal thoracic artery grafts has been suggested as a technique that results in less devascularization of the sternum [15]. Although we used sBITA grafts, the blood supply to the sternum may be somewhat decreased after the harvest of sBITA, which may delay sternal healing. Third, the use of bone wax may delay sternal closure. Vestergaard et al. [10] documented that bone healing was significantly impaired in patients treated with bone wax compared to both controls and patients treated with water-soluble polymer wax at three and six months postoperatively. We have generally used bone wax for hemostasis, especially in the manubrium, which may explain why the healing was poorest in the manubrium. Dasika et al. [16]

have demonstrated that the lower sternum is the most unstable site and that reinforcement of this area with an additional wire effectively stabilizes the closure. We usually use eight to 10 wires and almost always close the sternoxyphoid junction to stabilize the lower sternum. This may explain why the lower sternum did not have the poorest healing in our cases.

Our results indicate that the risk factors for poor early healing are a shorter period after operation, older age, diabetes mellitus, and postoperative renal dysfunction. Old age, diabetes mellitus, and renal dysfunction are well-known risk factors for postoperative sternal wound complications [17,18]. Therefore, we conclude that the risk factors for delayed sternal healing may be similar to those for sternal wound complications.

Our results demonstrated that the sternum healed completely in almost all patients undergoing CABG using sBITA within two years after the operation. We also showed that almost all patients had complete long-term sternal healing despite poor early sternal healing. These findings suggest that the use of sBITA does not cause significant problems for long-term sternal healing and that the presence of risk factors may not be a contraindication for the use of sBITA.

This study has some limitations. It is a retrospective observation of a subset of patients who underwent isolated CABG using sBITA. Despite these limitations, we conclude that complete sternal healing takes more than three months after a median sternotomy for CABG using sBITA and that healing is most delayed in the manubrium. However, almost all patients showed complete sternal healing 24 to 48 months after the operation and delayed early healing did not affect the long-term healing outcome. Our results provide baseline data for investigating the impact of different methods of sternal closure and the association between poor sternal healing and prolonged wound pain.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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