The Heart Surgery Forum 2022-4957
25 (6), 2022 [Epub November 2022]
doi: 10.1532/hsf.4957

Online address: http://journal.hsforum.com

# A Partial Clamp During Off-Pump Coronary Artery Bypass Grafting Can be Safely Used When Utilizing the Calcium Score with Computed Tomography For Evaluating The Ascending Aorta

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## ABSTRACT

**Background**: No previous study has shown that the volume of calcium score is useful for evaluating the aorta when performing a partial clamp (PC). The purpose of this study was to examine the effect of different clamping strategies during off-pump coronary artery bypass grafting (OPCAB), in terms of the incidence of postoperative stroke using the calcium score of the ascending aorta.

**Methods**: We retrospectively reviewed 339 patients, who underwent isolated OPCAB between August 2013 and March 2021. There were two groups of patients, depending on the procedure. A PC was used for proximal anastomoses in 130 (38.3%) patients. A clampless proximal facilitating anastomotic device (CFD) was used in 107 (31.5%) patients. We prescribed preoperative CT for all patients, and the Agatston score was used.

**Results**: The calcium score significantly was higher in the CFD group than in the PC group (29.7 ± 66.5 vs. 1819.8 ± 2391.5, < 0.001). The number of distal anastomoses and operative time were not significantly different between the two groups. There was no mortality and three strokes occurred at the 30-day follow up. Two strokes occurred in the PC group (1.5%) and one in the CFD group (0.9%), which was not significantly different ($P$ = 0.98).

**Conclusion**: A PC does not increase postoperative stroke incidence compared with a CFD, when utilizing calcium score evaluation in OPCAB.

## INTRODUCTION

Postoperative stroke (PS) is one of the most severe complications of coronary artery bypass grafting (CABG). Once PS occurs, the mortality rate increases to 32.8% and leads to increased morbidity and length of hospital stay [Anyanwu 2007]. Thus, it is necessary to determine a strategy for preventing PS. The risk of PS in CABG was reported as 1.1% to 3.5% [Head 2018; Morh 2015]. Some reports recorded that the manipulation of the ascending aorta was an independent risk factor for PS [Lev-Ran 2004; Lorusso 2019]. Not manipulating the ascending aorta is ideal but it may cause incomplete revascularization, and the number of distal anastomoses is smaller in those undergoing an aortic no-touch procedure. While using free grafts, we use two techniques for proximal anastomosis: a partial clamp (PC) and a clampless proximal facilitating anastomotic device (CFD) technique. Moss et al. reported that a CFD reduces the incidence of PS [Moss 2015]. However, we believe that a PC is an easily performed and safe method. We prefer to use a PC as a first-line choice if the ascending aorta is carefully assessed. Our evaluation of the ascending aorta used the volume of calcium score by utilizing preoperative CT and epiaortic ultrasonography (EU). Almost all of the studies that evaluated the ascending aorta used digital palpation and intraoperative echocardiograms [Lev-Ran 2004; Moss 2015]. We believe that these methods are not enough because EU results usually are evaluated by a surgeon, the evaluation is prone to errors, and the surgeon cannot evaluate the whole ascending aorta. In contrast, CT reveals aortic wall calcification in the whole area. Therefore, we chose either a PC or CFD or the no-touch technique using preoperative CT and EU. No previous study has shown that the volume of calcium score is useful for evaluating the aorta when performing a PC. Therefore, the purpose of this study was to prove that the PC could be utilized safely for the evaluation of the ascending aorta by using preoperative CT.

## MATERIALS AND METHODS

This study was approved by the Institutional Ethics Committee (approval number: THC200410). Between August 2013 and March 2021, 349 patients underwent isolated elective CABG at a single Japanese institution.

Ten patients undergoing on-pump CABG were excluded, including those undergoing on-pump conversion. We performed preoperative CT for all patients within one month before surgery. We utilized the Agatston score for evaluating the ascending aorta and intraoperative epiaortic echographic scanning for the ascending aorta [Blauth 1995]. Off-pump coronary artery bypass grafting (OPCAB) was performed

*Received June 25, 2022; accepted August 17, 2022.*

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for the 339 patients. Among those, a PC was used for proximal anastomoses in 130 (38.3%) patients (Group P). A CFD was used in 107 (31.5%) patients (Group C). The other 102 patients (31.2%) underwent total arterial grafts without aorta manipulation; 29 of them underwent minimally invasive direct coronary artery bypass (8.5%). From this excluded group, patients who had a high risk of stroke due to severe calcification at the ascending aorta were included. To avoid surgeons' bias, several cardiovascular surgeons consulted the preoperative CT to determine the methods of proximal anastomoses.

**Strategy for proximal anastomosis**: The proximal anastomosis procedure was modified, according to the results of preoperative CT scanning. Before August 2013, we did not calculate the calcium score at the ascending aorta. PS was observed in seven (1.7%) out of 420 cases of OPCAB between October 2007 and July 2013. We evaluated the calcium scores of PS patients retrospectively; the minimum calcium score was 482. In this study, patients with a calcium score over 300 points at the ascending aorta and those who had calcium spots at the site of the PC were selected to undergo procedure with a CFD. Even if there were no calcium spots at the clamp site, a PC could not be used in the cases wherein EU detected atherosclerosis. Heartstring (Guidant Corporation, Santa Clara, CA, USA) was selected for specific patients. Epiaortic echography was used for deciding the CFD site.

**Definitions of brain infarction**: Stroke was defined as a new neurologic deficit that appeared and remained, at least partially evident for more than 24 hours after its onset, and that occurred during or after the CABG procedure. Moreover, strokes need to be diagnosed before discharge. In addition to using the clinical symptoms, the diagnosis was confirmed by a neurologist by using brain imaging. Patients with transient ischemic attacks, intellectual impairment, confusion, or irritation were excluded.

**CT imaging protocol and analysis**: All patients were scanned using a 256-slice scanner (Brilliance CT; Philips Medical Systems, Eindhoven, Netherlands) at the Toyohashi Heart Center. A non-contrast multi-slice CT scan was performed to measure calcium score at the ascending aorta, according to the Agatston method [Agatston 1990]. Prospective electrocardiogram triggering was used with a slice thickness of 3.0 mm. The scan was performed between the neck and the diaphragm with the following parameters: collimation width, 32 × 0.625 mm; rotation time, 270 mms; tube voltage, 120 kV; and maximum effective tube current, 64 mA. Image reconstruction was gated prospectively to 75% of the R–R interval. Multi-slice CT images were reconstructed using a cardiac standard filter with a slice thickness of 3 mm. CT data sets were transferred to an offline workstation (Intelli Space Portal; Philips Medical Systems) for image analysis. The ascending aorta calcium score was determined 2-dimensionally by using the calcium score data sets on the workstation and defined by Agatston units (AU). The start of acquisition was from the origin of the innominate artery to the level of the sinotubular junction. A representative example of an ascending aorta calcium score assessment is shown in Figure 1. (Figure 1)

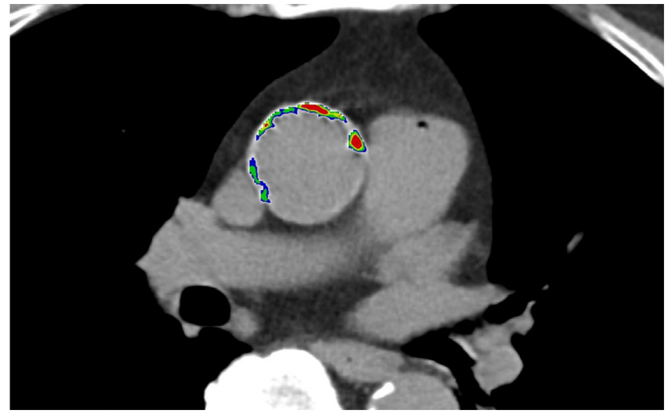

Figure 1. The calcium score of the ascending aorta using preoperative thin-slice CT.

**Surgical method**: OPCAB was performed through a median sternotomy. Both internal mammary arteries were harvested to the maximum extent possible by using the full skeletonized method using a Harmonic Scalpel (Ethicon, Cincinnati, Ohio, USA). The saphenous vein was selected as the free graft and harvested via the open or endoscopic method. Heparin intravenously was administered after internal mammary artery harvesting to maintain an activated clotting time of more than 200 seconds, and it was neutralized at the end of the procedure with protamine sulfate. Distal anastomoses were performed by this technique; the internal thoracic artery was utilized to the left anterior descending artery. Side-to-side anastomosis to the left-sided coronary artery was performed using a continuous 8-0 polypropylene suture. End-to-end anastomosis to the right coronary artery was performed using a continuous 7-0 polypropylene suture. Proximal anastomosis of the free grafts to the aorta was performed with 6-0 polypropylene sutures with the end-to-side approach. All saphenous vein grafts were attached to the ascending aorta. OPCAB clamping strategies for proximal anastomoses included either a single PC or the clampless technique with a CFD (Heartstring; Maquet Cardiovascular, San Jose, California). Blood in the operative field was collected by suction catheters and returned using a cell-saving device (HAEMONETICS, Braintree, Massachusetts, USA).

A PC was placed partially across the ascending aorta. To avoid aortic injury, a mean arterial blood pressure of <70 mmHg was achieved. This clamp was positioned with a sufficient portion of the ascending aorta to allow for several aortotomies for vein graft anastomoses. The anatomy was created by incising the excluded aorta wall with a pointed scalpel, after which an aorta wall punch of variable size was used to create the aortotomy.

HEARTSTRING consists of a specialized aortic cutter, delivery device, and proximal seal. In this technique, the arterial blood pressure was controlled same as the PC. Then, the aortotomy was created with the aortic cutter. The proximal seal was delivered into the aorta through the hole. After the seal system was unfolded within the aorta, the proximal anastomosis was performed.

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**Statistical analysis**: The demographics of the patients and outcome variables were expressed either as a percentage of the total or as mean ± standard deviation. Group comparisons were performed using a two-tailed Student's t-test and the Wilcoxon rank sum test for continuous variables. Categorical variables were compared using the chi-square test. A P-value of less than 0.05 was considered to be statistically significant. All statistical analyses were performed using SPSS version 22 software (SPSS, Inc., Chicago, IL, USA).

## RESULTS

The patient characteristics of each group are shown in Table 1. (Table 1) The traditional risk factors for stroke were comparable. There were no differences in the patients' preoperative variables such as age (69.5 ± 9.3 vs. 71.3 ± 9.3, $P$ = 0.12), history of previous stroke (8.5 % vs. 13.1%, $P$ = 0.173), and atrial fibrillation (2.3 % vs. 4.6 %, $P$ = 0.52) between the PC and CFD groups. The STS predicted risk of PS score also was not significantly different. There was a significant difference in the calcium scores (29.7±66.5 vs. 1819.8±2391.5, $P$ < 0.001). In the PC group, the range of calcium scores was 0 to 271, and in the CFD group, it was 267 to 65558. The operative data are shown in Table 2. (Table 2) The results of operative time, number of anastomoses, and postoperative atrial fibrillation were not significantly different. There were no mortalities, and three strokes occurred within three days postoperatively. The strokes corresponded to two strokes in the PC group (1.5%) and one stroke in the CFD group (0.9%), which was not significantly different ($P$ = 0.573). All strokes occurred postoperatively, and the profile of each stroke patient is shown in Table 3. (Table 3) Two patients in the clamp group had no calcium score, but had several risks for stroke, such as postoperative atrial fibrillation.

Table 1. Patient characteristics

| | Group P ($N$ = 130) | Group C ($N$ = 107) | P-value |
|---|---|---|---|
| Age (years) | 69.5 ± 10.5 | 71.3 ± 9.3 | 0.12 |
| Male | 85 (65.3%) | 50 (46.7%) | 0.35 |
| BMI (kg/m2) | 24 ± 3.5 | 23.4 ± 4 | 0.248 |
| Hypertension | 82 (63%) | 67 (63.6%) | 0.788 |
| Prior stroke | 11 (8.5%) | 14 (13.1%) | 0.173 |
| Cereobrovascular disease | 21 (16.1%) | 19 (17.7%) | 0.16 |
| Peripheral vascular disease | 16 (12.3%) | 19 (17.8%) | 0.272 |
| Diabetes mellitus | 75 (57%) | 63 (58.9%) | 0.48 |
| Ejection fraction | 58.5% | 58% | 0.39 |
| Serum creatinine (mg/dl) | 1.85 ± 2.2 | 2 ± 2.5 | 0.65 |
| Atrial fibrillation | 3 (2.3%) | 5 (4.6%) | 0.52 |
| Dialysis | 19 (14.6%) | 15 (14%) | 0.524 |
| Calcium score | 29.7 ± 66.5 | 1819.7 ± 239.5 | <0.001 |
| PROM | 2.2± 2.6 | 2.5 ± 1.9 | 0.69 |
| PROPS | 1.85 ± 1.1 | 2.03 ± 1.3 | 0.86 |
| Smoker | 13 (10%) | 11 (10.2%) | 0.523 |
| Prior PCI | 36 (27.7%) | 31 (28.9%) | 0.47 |

PROM, STS predicted risk of mortality; PROPS, predicted risk of postoperative stroke; BMI, body mass index; PCI, percutaneous coronary intervention

## DISCUSSION

The findings of this study suggest that PC methods, compared with a CFD, do not increase PS incidence through adequate evaluation of the ascending aorta. This is the first study that showed preoperative aortic evaluation using calcium scores with CT for the ascending aorta was useful for preventing PS and that aortic clamping can be safely performed in patients with a normal or mildly atherosclerotic aorta.

PS is one of the most disabling complications of CABG. The manipulation of a diseased ascending aorta causing atheromatous debris and leading to cerebral embolism was thought to be the mechanism of stroke [Blauth 1995]. Patients with adverse cerebral outcomes had higher in-hospital mortality. The in-hospital mortality rate was 21% of patients with adverse cerebral outcomes [Roach 1996]. Therefore, a strategy for preventing cerebral injury is important. Some risk factors for PS, such as advanced age, diabetes, a previous clinical history of cerebral infarction, extended cardiopulmonary bypass, and a PC clamp, have been reported [Manabe 2009; Bucerius 2003].

The aortic no-touch technique is an effective method for reducing stroke incidence [Vallely 2008]. However, this strategy restricted free graft selection, and it might reduce the number of anastomoses. We might need to use free graft and proximal anastomosis for the ascending aorta, especially in patients with multi-vessel diseases; thus, complete revascularization is a primary goal.

Table 2. Operative data

| | Group P ($N$ = 130) | Group C ($N$ = 107) | P-value |
|---|---|---|---|
| Operation time (min) | 254.1 ± 48.9 | 241.8 ± 45.8 | 0.052 |
| Number of distal anastomoses | 3.4 ± 0.9 | 3.2 ± 0.8 | 0.13 |
| Atrial fibrillation | 26 (20%) | 25 (23.3%) | 0.319 |
| Blood cell transfusion | 46 (35.3%) | 51 (47.6%) | 0.064 |
| Length of hospital stay (days) | 11.3 ± 6.4 | 11.3 ± 5.8 | 0.95 |
| Stroke | 2 (1.5%) | 1 (0.9%) | 0.573 |
| Aortic dissection | 0 | 0 | |
| 30-day mortality | 0 | 0 | |
| Sternal wound infection | 1 (0.7%) | 1 (0.9%) | 0.7 |

Table 3. Characteristic of each stroke patient

| Patient number | Clamp method | Age | Symptom | Stroke onset time | Calcium score | PROPS | Stroke risk factors |
|---|---|---|---|---|---|---|---|
| 1 | Partial clamp | 80 | hemianopia | POD 1 | 0 | 1.13 | POAF |
| 2 | Partial clamp | 54 | paralysis | POD 6 | 0 | 2.79 | POAF, prior stroke |
| 3 | CFD | 72 | dysarthria | POD 0 | 1202 | 3.97 | prior stroke, cerebral vascular disease |

CFD, clampless facility device; POD, postoperative day; PROPS, predicted risk of postoperative stroke; POAF, postoperative atrial fibrillation

There were two methods for proximal anastomosis for the ascending aorta: a PC and CFD, using free grafts in off-pump CABG. A CFD is not necessary for aortic clamping. Douglas et al. reported a stroke rate of 0.8% for OPCAB in combination with a CFD [Douglas 2009]. The authors stressed on the role of clampless OPCAB as an important tool for the prevention of PS and also concluded that adjunctive techniques for the prevention of emboli from the ascending aorta may further reduce the risk of stroke. Emmert et al. showed that the occurrence of stroke and MACCE can be significantly reduced by using the HEARTSTRING device, yielding results similar to those that can be achieved with no-touch total arterial in-situ grafting [Emmert 2013]. However, a CFD is expensive and necessitates more cumbersome manipulation. Performing a CFD procedure has risks of bleeding and air embolism [Vicol 2005; Nollert 2003]. Manabe et al. suggested that during anastomoses with a CFD, solid atherosclerotic material might be fragmented when the connector penetrates the aorta, and an increased number of gas bubbles might be sucked into the bloodstream during connector attachment [Manabe 2009]. In contrast, a PC is an easy and cost-effective method and can easily be used to create anastomoses because it is bloodless and has a wide work space; thus, we prefer to use a PC as the first choice. Although a PC is a risk factor for stroke, especially in patients with a high atherosclerotic burden in the ascending aorta [Moss 2015], the issue is whether a PC for patients who had no or a low-grade atheroma at the ascending aorta might become a risk factor. Several studies showed that a CFD can reduce the risk for PS. However, the ascending aorta was evaluated by only echography [Lev-Ran 2004; Moss 2015; Manabe 2009]. EU during OPCAB was widely used for the screening of atherosclerotic diseases of the ascending aorta, and it was useful for preventing PS. Hisham found that there was a lower incidence of stroke in the CFD group than in the PC group when using EU [El Zayat 2012]. In contrast, Manabe et al. also evaluated diseases of the ascending aorta using EU and stated that aortic PC can be performed safely in patients with normal or mildly atherosclerotic aortas compared with the CFD groups (stroke ratio: 0.8% vs. 2.8%) [Manabe 2009]. The adverse effects of a PC, such as stroke, are controversial when using this tool. We thought that if we could adequately detect ascending aortic diseases and eliminate the high risk of aortic manipulation, PC would be an acceptable method. Some reports stated that echography is a reliable technique for the detection or characterization of atheromas [Manabe 2009; Moss 2015; El Zayat 2012], but we thought that it was difficult for detecting all aortic atheroma diseases. This is due to the fact that echography has a disadvantage of near-field distortion. In addition, determination of the plaque extent or complexity may be limited, because only one plane can be visualized or measured at a time.

The wide range of ultrasonographic detection rates (21%-62%) suggests that this method is usually based on the surgeon's evaluation, which lacks objectivity and has potential for errors [Wareing 1992; Wilson 2000]. To acquire more information, we performed routine preoperative CT. Enhanced CT can detect the thickness of the aortic wall, but renal damage and allergy may occur. Many patients with coronary diseases had CKD; thus, a routine procedure was unacceptable. Instead of enhanced CT, 5-mm slice CT was performed to calculate the calcium score at the ascending aorta. The calcium score is widely used to detect lesions due to coronary artery diseases. CT has advantages, such as sensitivity, specificity, accuracy for identifying atheromas, and the ability to scan the entire aorta to assess overall plaque burden. Furthermore, to compensate for the disadvantages of CT, we augmented it with intraoperative epiaortic echography to detect the degree of atheromas, atheroma size, and mobility. We chose the proximal anastomosis method and combined these tools. There was no clear evidence that the degree of calcium scores was dangerous for a PC. In this study, we assigned a cutoff point of 300 degrees to determine whether we could safely perform a PC. Previously in this study, we evaluated the preoperative CT only using eye ball methods, and a few patients were observed as having PS. We evaluated the preoperative CT in these patients retrospectivity; the minimum calcium score was 482 units. Although the cause of stroke was not only a PC, we determined the cutoff point as approximately 300 units, considering the safety margin.

In addition, there were two patients in whom stroke occurred in the PC group, but both were diagnosed a few days later (one patient had hemianopia at POD 1, and another had paralysis at POD 6); thus, we believe that none of the patients were directly affected by the PC. Two patients had postoperative arterial fibrillation; thus, we believe that it affected the occurrence of cerebral ischemia. We thought that we could identify patients with a diseased ascending aorta utilizing a CT scan and the calcium score. A PC can safely be utilized during preoperative CT and can be selected as a first-line treatment for patients with a normal ascending aorta.

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This study has some limitations. First, this was an observational study. Second, the number of patients was small, and the incidence of stroke was too low. Thus, further studies with larger sample sizes are necessary. However, this study is the first to report that the calcium score is useful for evaluating the ascending aorta when performing a PC during CABG. Third, this study may have potential biases, due to the patients' backgrounds. Although, we evaluated the STS stroke score and found no significant difference between the two groups, patients in the PC group had mild vascular calcification with no plaque, and their degree of coronary heart disease may also have been relatively mild with relatively better vascular conditions. Thus, there was baseline bias between the two groups.

In conclusion, a PC does not increase the risk for PS compared with a CFD when utilizing calcium score evaluation through OPCAB. To safely create a proximal anastomosis by a PC, preoperative CT can be a useful tool for preventing PS.

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