Coronary endarterectomy in patients with diffuse coronary artery disease: assessment of graft patency with computed tomography angiography

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Background: With a growing population of patients with advanced coronary artery disease (CAD), many of whom have undergone prior percutaneous coronary interventions, coronary endarterectomy (CE) allows for the extension of revascularization in patients with otherwise limited options. Whether adjunctive CE associated with standard surgery, combined with contemporary antiplatelet therapy, improves outcomes remains largely unknown.

Methods: We studied 147 consecutive patients who underwent 154 adjunctive CE procedures for advanced CAD between January 2015 and January 2018. We used computed tomography angiography (CTA) in a subgroup of 32 consecutive patients who underwent CE during coronary artery bypass grafting after June 2016 to assess graft and coronary patency.

Results: Patients (mean age 67 ± SD 10 yr) underwent CE of the right (102 patients), the left anterior descending (LAD, 22 patients) and the circumflex (17 patients) coronary arteries. Seven patients (5%) experienced a procedural myocardial infarction and there were no perioperative deaths. Among the 32 patients who underwent CTA 3 months after surgery, the mean patency of the endarterectomized coronary arteries and bypass grafts was 90% and 88%, respectively. All 6 arterial grafts on the LAD artery were patent. The mean survival rate and the mean rate of freedom from major adverse cardiovascular events was 95% ± 2% and 95% ± 6%, respectively. The patency rate was 100% for patients evaluated at 3-year follow up.

Conclusion: Coronary endarterectomy offers a surgical option for patients with diffuse CAD who may be unsuitable for coronary bypass alone. Grafts and endarterectomized coronary artery patency remain adequate and explain the excellent patient survival and the freedom rate from major adverse cardiovascular events.

Contexte : Avec une population croissante de patients atteints de coronaropathie avancée (CA), dont plusieurs ont déjà subi des interventions coronariennes percutanées, l’endartériectomie coronarienne (EC) permet d’améliorer la revascularisation chez les patients pour qui les options sont par ailleurs limitées. On ignore si l’EC d’appoint associée à la chirurgie standard et alliée au traitement antiplaquettaire moderne permet d’améliorer les résultats.

Méthodes : Nous avons étudié 147 patients consécutifs qui ont subi 154 EC d’appoint pour une coronaropathie avancée entre janvier 2015 et janvier 2018. Nous avons utilisé la coronarographie chez un sous-groupe de 32 patients consécutifs soumis à une EC durant un pontage aortocoronarien après juin 2016 pour évaluer la perméabilité du greffon et des coronaires.

Résultats : Les patients (âge moyen 67 ans ± écart-type [É-T] 10 ans) ont subi une EC de la coronaire droite (102 patients), de la descendante antérieure gauche (22 patients) et de la circonflexe (17 patients). Sept patients (5 %) ont subi un infarctus du myocarde durant l’intervention et on n’a déploré aucun décès périopératoire. Parmi les 32 patients qui ont subi une coronarographie 3 mois après la chirurgie, la perméabilité moyenne des coronaires soumises à l’endartériectomie et des greffons était de 90 % et de 88 %, respectivement. Les 6 greffons artériels de la descendante antérieure étaient perméables. Les taux moyens de survie et de survie sans événement cardiovasculaire majeur ont été de 95 % ± 2 % et de 95 % ± 6 %, respectivement. Le taux de perméabilité était de 100 % chez les patients évalués au bout d’un suivi de 3 ans.

Conclusion : L’endartériectomie coronarienne offre une option chirurgicale aux patients qui ont une coronaropathie diffuse et qui seraient de mauvais candidats au pontage aortocoronarien seul. La perméabilité des greffons et des coronaires endartériectomisées reste adéquate et explique l’excellente survie des patients et l’absence d’événements cardiovasculaires majeurs.

Patients with advanced coronary artery disease (CAD) are poor candidates for coronary revascularization. A coronary artery that is diffusely infiltrated with poor distal runoff is typically not amenable to percutaneous coronary intervention (PCI). Coronary artery bypass grafting (CABG) remains a marginal option.[1] In such instances, complete revascularization may not be achieved in a substantial proportion of these patients.[2] As a result, a large contingent of patients may have post-revascularization angina, a suboptimal quality of life and a poor prognosis.

Surgical coronary endarterectomy (CE) was introduced as an isolated procedure for myocardial revascularization in the late 1950s.[3] Its exact role and impact as an adjunct to CABG remains disputed. Early experiences with CE reported a high perioperative morbidity and mortality, but recent data suggest that it can be performed safely with good early clinical results.[4,5]

To ensure optimal and complete myocardial revascularization in some patients with diffuse CAD, surgeons have reconsidered the use of adjunct CE combined with conventional CABG. Our study provides an evaluation of the use of CE in current CABG surgery. Although postoperative assessment of a patient who underwent cardiac surgery is traditionally performed with catheter angiography, the risk of this technique (e.g., stroke, hemorrhage and technical difficulties in accessing surgical grafts) qualifies its clinical usefulness. Advances in computed tomography (CT) have enabled imaging of CAD and the evaluation of CABG. Computed tomography angiography (CTA) was used to assess graft and target coronary artery patency after surgery.

Methods

Patient population

Between January 2015 and January 2018, 147 patients underwent 154 adjunctive CE procedures for advanced CAD in our institution. Patients were either symptomatic (e.g., angina, dyspnea or both) or showed objective evidence of myocardial ischemia (e.g., positive imaging with or without depressed left ventricular function) and deemed candidates for surgical coronary revascularization. Performing CE was based on the results of preoperative coronary angiography and intraoperative findings of the target coronary artery. Coronary endarterectomy was selectively chosen for diffusely diseased major coronary arteries or their major branches (external diameter ≥ 1.5 mm). Coronary endarterectomy was performed only when the atheromatous plaques were severe and circumferential and could not be excluded by extensive reconstruction without CE. On some occasions, CE was the only solution as needles could not penetrate the severely calcified plaques and vessel walls to ensure a proper surgical anastomosis. Coronary endarterectomy was also performed along with stent removal for long segment in some patients with intra-stent restenosis (8 of 147 [5.44%]). Coronary endarterectomy was not attempted if the diseased vessel supplied a myocardial territory that was fibrotic, akinetic or showed a fixed perfusion defect on angiography or in scintigraphy.

All patients were informed of the procedural risks and options of CABG surgery and signed the informed consent for the intervention. Our study was approved by the institutional review board and ethics committee of our centre. Patient consent for inclusion in our study was waived.

Data collection and follow up

Baseline demographic characteristics, medical history, cardiac catheterization data and perioperative data were retrospectively abstracted from electronic medical records and dedicated databases. Surgical risk was stratified using the logistic EuroSCORE. The estimated average risk was 1.74%. Follow up occurred at regular intervals in the outpatient clinic at 3–6 months after CABG surgery and was completed in 99% of patients.

Clinical definitions

Operative death was defined as death occurring during hospital admission or after discharge within 30 days of surgery. Major adverse cardiac and cerebrovascular events were defined as all-cause death, cerebrovascular accidents, nonfatal myocardial infarction (MI) and repeat revascularization. Perioperative MI was defined as a positive result for new Q waves, an evolutionary ST-segment elevation in 2 continuous electrocardiogram leads, a new left bundle branch block or as a creatine kinase-myocardial band level of 5 or more times the upper limit of normal or new wall motion abnormality at echocardiogram. Respiratory failure was defined as the requirement for prolonged mechanical ventilation (> 48 h) or the presence of pneumonia. Postoperative stroke was defined as the occurrence of a new neurological deficit and confirmation by CT. In patients with preoperative stroke, postoperative stroke was defined as worsening neurological deficit with new radiological findings.

Coronary endarterectomy and CABG surgery

Procedures were performed through a median sternotomy. Among the 147 patients, 136 (93%) underwent on-pump CABG surgery, whereas 11 (7%) underwent off-pump CABG surgery.

Internal mammary arteries (IMA) and greater saphenous veins were used for grafts. Coronary endarterectomy was performed when the target vessel to revascularize was severely calcified and anastomosis was not technically possible. All vessels undergoing endarterectomy were judged to be poor candidates for a distal coronary anastomosis.

Direct-vision endarterectomy was performed consistently for the diffusely diseased coronary artery. After coronary arteriotomy, an endarterectomy spatula was used to identify the plane of dissection between the plaque and the artery and then to mobilize the plaque proximally and distally. A 1 mm probe was advanced gently through the plane of dissection to break away adhesions. A combination of gentle traction on the plaque and counter traction on the adventitia of the coronary artery was used to extract the plaque distally and proximally to a long coronary arteriotomy of 8–10 mm.

The distal end of a spatulated saphenous vein graft or the IMA was used for revascularization and arteriotomy closure. Patch closure of the arteriotomy with a saphenous vein or with an IMA grafted to the patch was used when necessary.

Computed tomography angiography protocol

Patency of grafts and coronary arteries was assessed using CTA in 32 patients who were prospectively studied from June 2016 to January 2018. The examination was performed 3 months after CABG surgery.

All studies were performed with a dual source, dual energy 384-slice (2 × 192 slices) Siemens Somatom Force CT scanner using helical prospective cardiac electrocardiogram-gating, high-pitch technique. Patients received 70 mL or 77 mL of iopamidol, (370 mg/mL intravenous contrast media) according to a patient's body mass index, with injection rates of 5 mL/s and 5.5 mL/s, respectively. Patients were also administered 0.8 mg of sublingual nitroglycerine before the scan. Intravenous metoprolol was given on a case-by-case basis at the discretion of the attending radiologist to slow the patient heart rate (60–70 bpm). Patients were monitored for the duration of the scan. Images were acquired in the arterial phase from lung apices to the base of the heart to ensure complete coverage of the coronary grafts with a selected slice thickness of 0.6 × 0.4 mm. Evaluation of grafts and coronary arteries was performed by trained radiologists on multiplanar reformats using dedicated 3D reconstruction software (Syno.via, Siemens).

Statistical analysis

All analyses were performed using IBM SPSS statistics version 25.0 (IBM Corp.). Continuous data are presented as mean ± standard deviation (SD) and skewed continuous variables are expressed as the median with the range. Categorical variables are presented as a frequency or proportion. A bivariable logistic correlation was conducted to examine the interaction between the graft patency and the anticoagulation antiplatelet regimen.

Actuarial analysis was performed to study patient survival. Cumulative survival rate and the major adverse cardiac and cerebrovascular events-free rate were estimated using the Kaplan–Meier method.

Results

Clinical results

Patient demographics and preoperative characteristics are presented in Table 1. The mean age of patients was 67 ± 10 years and the majority were male (n = 120, 81%). Thirty-two (22%) patients had undergone PCI before surgery and 4 (3%) patients underwent repeat CABG surgery.

Triple bypass was performed in 91 patients (62%) and quadruple bypass in 33 (22%) patients (Table 2). Coronary endarterectomy was performed on the right coronary artery (RCA) in 108 patients (70%), a marginal branch of the circumflex coronary artery in 22 patients (14%), the left anterior descending (LAD) coronary artery in 21 patients (14%) and diagonal branches in

Table 1. Preoperative patient characteristics

Characteristic	No. (%) of patients* n = 147
Age, yr, mean ± SD	67 ± 10
Range	41–85
Female, n (%)	27 (19)
Cardiac risk factors	
BMI (kg/m^2), mean ± SD	29.6 ± 5.2
Hypertension	126 (86)
Diabetes mellitus	76 (52)
Hypercholesteromia	139 (95)
History of smoking	89 (61)
Stage IV renal failure	4 (2.7)
Angina class	
CCS I	30 (21)
CCS II	50 (34)
CCS III	52 (35)
CCS IV	15 (10)
Functional class	
NYHA I	30 (20)
NYHA II	67 (46)
NYHA III	35 (24)
NYHA IV	15 (10)
Previous PCI	32 (22)
EuroSCORE II, median (range)	1.74 (0.55–10)
Previous cardiac surgery	4 (3)
Perioperative status	
Elective	94 (64)
Urgent	46 (31)
Emergency	7 (5)

BMI = body mass index; CCS = Canadian Cardiovascular Society; EuroSCORE II = European System for Cardiac Operative Risk Evaluation; NYHA = New York Heart Association; PCI = percutaneous coronary intervention; SD = standard deviation.
*Unless indicated otherwise.

Table 2. Operative data

Variable	No. (%) of patients*
No. of grafts (venous and arterial)	
On-pump	
1	2 (1)
2	15 (10)
3	86 (59)
4	29 (20)
5	4 (3)
Off-pump	
1	0
2	2 (1)
3	5 (4)
4	4 (3)
5	0
Endarterectomy site	
RCA	108 (70)
LAD	21 (14)
Diagonal	3 (2)
LCx (M1–M2)	22 (14)
No. of endarterectomy	
1 vessel	141 (96)
2 vessels	5 (3)
3 vessels	1 (1)
Cardiopulmonary bypass, min, mean ± SD	79.8 ± 32.1
Aortic cross-clamp, min, mean ± SD	56.1 ± 26.5
Total intraoperative blood loss, mL, mean ± SD	390 ± 170
Concomitant procedures, *n*	14
AVR	11
MVR	2
LV aneurysmectomy	1

AVR = aortic valve replacement; LAD = left anterior descending; LCx = left circumflex; LV = left ventricle; M1 = first marginal artery; M2 = second marginal artery; MVR = mitral valve repair; RCA = right coronary artery; SD = standard deviation.
*Unless indicated otherwise.

Table 3. Postoperative data

Outcome	*n* (%)*
Postoperative IABP	5 (3.4)
Intensive care unit stay, d, mean ± SD	2.8 ± 2
Postoperative hospital stay, d, mean ± SD	7 ± 4
Maximum lactate level, mmol/L, mean ± SD	1.72 ± 1.2
Maximum CK-MB level, IU/L, mean ± SD	28.67 ± 29 (6–226)
Temporary hemodialysis	3 (2)
Postoperative AF	42 (29)
Postoperative bleeding requiring reoperations	8 (5)
Postoperative MI	7 (5)
Postoperative stroke	5 (3)
Postoperative delirium	13 (9)
Heart failure	9 (6)
Deaths within 30 d	0

AF = atrial fibrillation; CK-MB = creatine kinase-myocardial band; IABP = intra aortic balloon pump; MI= myocardial infarction; SD = standard deviation
*Unless indicated otherwise.

Table 4. Characteristics and outcomes of the 32 patients who underwent control CTA

Characteristic	*n* (%)
Type of graft	
IMA	6
SV	26
Site of endarterectomy	
RCA	25
LAD	6
LCx	1
Graft patency	32
IMA	6/6 (100)
SV	22/26 (85)
Target coronary artery patency	
Patent	29 (90)
Occluded	3

CTA = computed tomography angiography; IMA = internal mammary artery; LAD = left anterior descending; LCx = left circumflex; RCA = right coronary artery; SV = saphenous vein.

3 patients (2%). The arteriotomy was closed with saphenous vein patches before bypass grafting with an IMA graft in 13 patients (9%). Revascularization was complete with the addition of the endarterectomy in 128 patients (87%).

There were no hospital deaths after CABG surgery. Seven patients (5%) had a perioperative MI. Post-cardiotomy, intra-aortic balloon pump support was required in 5 patients (Table 3).

Patency of the grafts and of the endarterectomized coronary arteries

In the 32 patients who underwent a prospective control CTA 3 months after surgery, the endarterectomized coronary artery and the corresponding graft were patent in 29 (90%) and 28 (88%) patients, respectively (Table 4). All arterial grafts remained patent and 4 occlusions (12%) occurred in venous conduits anastomosed to the RCA or posterior descending artery.

Three years after surgery, a CTA was performed on only 9 patients who were evaluated in this prospective group (COVID restriction). The endarterectomized coronary artery (2 LAD and 7 RCA) and the corresponding graft were permeable in all cases.

Patient survival and survival free from reintervention

Two years following CABG, mean survival was 95% ± 2% (Figure 1). The mean freedom rate from angina, MI, congestive heart failure and hospital readmission was 97% ± 2% at 1 year and 95% ± 6% at 2 years, respectively (Figure 2). All patients with bypass occlusion identified on the CTA were alive at the last follow up and free from angina.

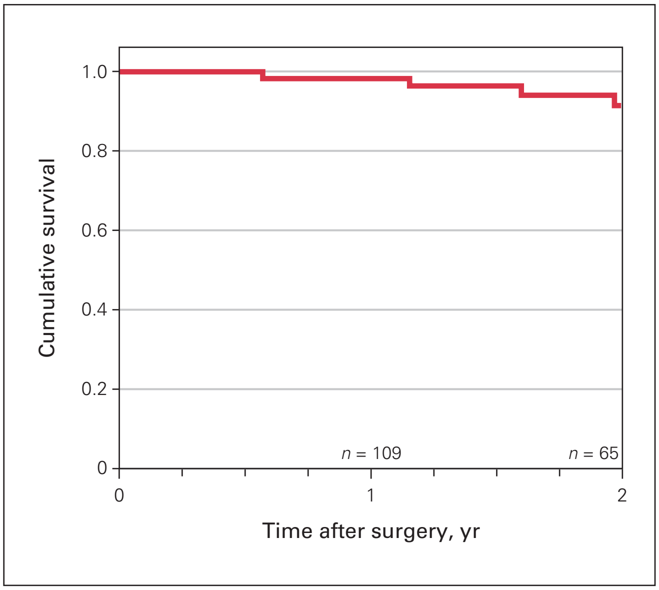

Fig. 1. Kaplan–Meier plot of actuarial survival for all patients after coronary endarterectomy.

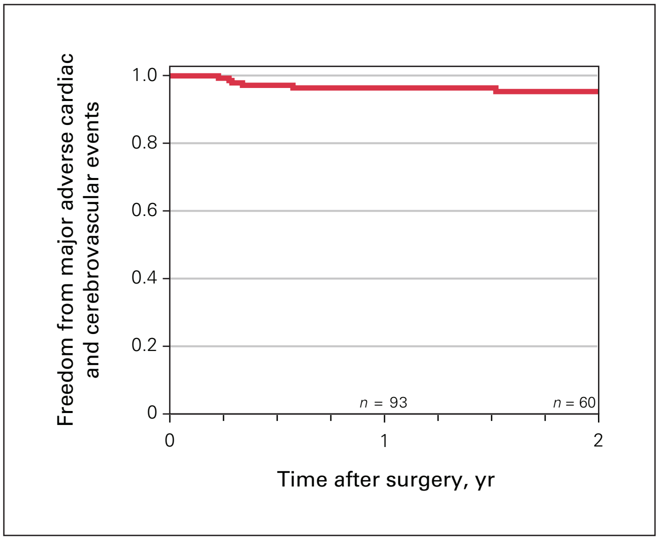

Fig. 2. Kaplan–Meier estimates of major adverse cardiac and cerebrovascular events.

Antiplatelet agents

All patients were postoperatively prescribed acetylsalicylic acid (ASA) or clopidogrel at the discretion of the attending surgeon (Table 5). Thirty-seven (25%) patients were prescribed a single antiplatelet agent and 107 (73%) patients received dual antiplatelet treatment (clopidogrel in 80 cases and ticagrelor in 27 cases). There was no difference in graft patency according to the different antiplatelet regimens used in the bivariate correlation analyses. There were no correlations between the variations in postoperative antiplatelet regimen (dual v. single antiplatelet agent) and graft patency ($r = 0.16$).

Table 5. Use of antiplatelet agents after surgery

Antiplatelet agent	*n*
Single dose, ASA	37
Dual	107
ASA + clopidogrel	80
ASA + other*	27
Three	3

ASA = acetylsalicylic acid.
*Other = ticagrolor and warfarin.

Discussion

Coronary artery bypass graft surgery remains the standard of care in the treatment of advanced CAD. Although, adjunctive CE is used occasionally, favourable clinical results have not been reported consistently.[6–8] Our study reports satisfactory clinical results in a group of patients with diffuse CAD who underwent CABG associated with adjunctive CE. Complete myocardial revascularization was achieved in 87% of patients. Angiographic assessment in a prospective performance showed at 3 months that surgical patency of grafts and endarterectomized coronary arteries averaged 88% and 90%, respectively.

A recent study used CTA to assess graft patency in patients who underwent coronary bypass surgery with 2 saphenous vein grafts, who were randomized either to standard care or to a specific preservation preparation in nonendarterectomized coronary arteries.[9] Of the 118 saphenous vein grafts performed, 108 (92%) were patent 3 months after surgery in patients randomized to standard care. In our study, 22 of 26 saphenous vein grafts (88%) anastomosed to endarterectomized coronary arteries were patent 3 months after surgery. Both studies showed similar results with CT performed 3 months after surgery in both endarterectomized and nonendarterectomized coronary arteries.

Coronary endarterectomy was first described by Bailey and colleagues[3] in 1957 and was shown to benefit patients with advanced CAD by allowing complete myocardial revascularization. The reported frequency of performing CE in association with CABG varies between 3.7% and 42%.[10,11] Adjunctive CE is an appropriate technique to revascularize, especially the RCA and the LAD artery, when wall calcification or extensive atherosclerotic changes prevent a good quality anastomosis.[11–13] In addition, although CE is not commonly planned before surgery, it remains an option to address coronary arteries that are calcified and severely diseased.

The main purpose of the endarterectomy is to extract the complete intima and the media containing calcification and atherosclerotic changes at the site of the arteriotomy and in the distal coronary artery bed, not only to perform an anastomosis, but also to ensure a better distal coronary blood flow. The quality of the distal endarterectomized vessel influences graft and artery patency.[14] The results of CE in terms of symptomatic relief, perioperative MI and mortality, are improving in parallel with the improvements in CABG. With the increasing incidence of diffuse CAD, CE is a useful tool to achieve complete revascularization.

To evaluate the early, mid- and long-term patency, CTA offers an accurate assessment of the coronary arteries, grafts and CE. The improved accuracy and safety of CTA may reduce the need for invasive coronary angiography.[15,16]

In 2007, Schwann and colleagues[17] reported excellent graft patency, averaging 91% in patients who underwent CE of the LAD artery and IMA grafting. All 6 IMA arterial grafts on the LAD artery with endarterectomy were patent 3 months after surgery. Schwann and colleagues reported a much lower patency with saphenous vein grafts after CABG surgery, whereas the use of the radial artery achieved a superior patency rate (59% v. 81%).

Stavrou and colleagues[18] suggest that thromboprophylaxis plays a central role in the medical management of patients after CE. Although some authors recommend a dual antiplatelet regimen with or without warfarin, there is no clear recommendation from guideline reviews of clinical practice.[19]

The CASCADE trial was a double-blind phase II trial undertaken to evaluate whether the addition of clopidogrel (75 mg) to ASA (162 mg) daily inhibits saphenous vein graft disease after CABG, as assessed at 1 year by intravascular ultrasonography. The study concluded that there was no benefit to the addition of clopidogrel to ASA regarding saphenous vein graft patency.[20] Although our study was not randomized, there was no correlation between the use of a double antiplatelet regimen and graft patency. It remains possible that a more aggressive antiplatelet therapy with newer and more potent agents could improve graft and target coronary artery patency after CE. The damage caused by the endarterectomy on the vessel wall leads to the exposure of the medial layer of the artery to circulating blood cells, a major stimulus for acute graft and coronary artery thrombosis.

Several authors[21–24] suggest the mortality and the morbidity associated with CABG surgery is higher in patients who undergo an adjunctive CE. In an analysis of 3369 patients who underwent CABG combined with CE, Livesay and colleagues[11] concluded that there was a small increase in surgical risk after endarterectomy. The 30-day mortality for bypass alone was 2.6%, compared with 4.4% for CE ($p < 0.01$). In 2005, Tiruvoipati and colleagues[21] concluded that there was a higher mortality rate and a greater incidence of postoperative renal impairment in patients who had CABG and CE. In 2014, Soylu and colleagues[23] conducted a meta-analysis of 20 studies including 54 440 patients (7366 CABG + CE; 47 074 CABG only) and concluded that adjunctive CE significantly increased 30-day mortality, perioperative and postoperative MI.

Our study suggests that adjunctive CE can be performed safely after surgery. The incidence of postoperative MI reported in the literature ranges from 5% to 25%.[18] These rate of MI in our study was low and acceptable but higher among patients who underwent CE than in those who underwent CABG alone.

Limitations

Our study was limited by the small number of patients who underwent CTA, which makes it difficult to generalize the results, despite CTA having been performed systematically during the study period.

Conclusion

Coronary endarterectomy is an acceptable adjunctive technique to CABG surgery for patients with extensive CAD to achieve complete myocardial revascularization. Careful surgical technique at the site of endarterectomy; proper selection of bypass grafts, particularly arterial grafts; and the optimal use of antiplatelet agents ensure high patency rates and appropriate clinical results in patients with extensive CAD.

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