Can Right Ventricular Branch Bypass Alleviate Right Ventricular Dysfunction?

Mehmet Ali Sahin, MD1; Mehmet Yokusoglu, MD2; Erkan Kuralay, MD1; Ertugrul Ozal, MD1

1Cardiovascular Surgery Department, Alife Hospital, Ankara, Turkey
2Cardiology Department, Alife Hospital, Ankara, Turkey

Background: Right ventricle (RV) dysfunction after a coronary artery bypass grafting procedure is a challenge that adversely affects RV filling pressure and contraction. This study sought to determine whether additional bypass of an RV branch would lessen RV dysfunction.

Methods: Patients with severe right coronary artery (RCA) stenosis were divided into 2 groups. Group 1 patients (n = 50) had a single distal bypass on the RCA. Group 2 patients (n = 50) had both distal RCA and additional bypass on the RV branch of the RCA. Right ventricular function was examined by echocardiogram by measuring transannular plane systolic excursion, fractional area change, tissue Doppler S-wave velocity, and inferior vena cava diameter.

Results: Transannular plane systolic excursion and fractional area change measurements rapidly decreased below the cutoff in both groups, but group 2 patient values reached normal limits at 90 days. Tissue Doppler S-wave velocity reached the normal limit in 7 days. Inotropy was required in 11 patients in group 1 and 2 patients in group 2 (P = .013). The mean (SD) intensive care unit stay was 2.11 (1.12) days and 1.45 (0.71) days (P = .033), and the hospital stay was 7.32 (1.44) days and 6.22 (0.45) days in groups 1 and 2, respectively (P = .027).

Conclusion: The data in this study suggest that an additional graft on the RV branch of the RCA (e.g., conus, marginal, any good runoff vessels on the RV) prevents severe RV dysfunction and allows for rapid recovery of RV dysfunction after off-pump coronary surgery. (Tex Heart Inst J. 2022;49(5):e217607)

Right ventricle (RV) dysfunction after a coronary artery bypass grafting (CABG) procedure is a challenge and adversely affects RV filling pressure and RV contraction.1-3 It has been proposed that factors including cardioplegia, aortic clamping, and pericardial disruption/adhesion related to the cardiopulmonary bypass (CPB) procedure are underlying causes of this condition. Right coronary artery (RCA) occlusions are mainly located in the proximal part of the RCA. Classical RCA revascularization consists of a single graft anastomosis. Right ventricular branch arteries mainly arise from the proximal part of the RCA. These arteries provide the main blood supply to the RV. This study investigated the effects of additional CABG of RV branch arteries on RV function and recovery of RV dysfunction after off-pump coronary surgery.

Patients and Methods

This study was approved by the Alife Hospital institutional review board, and informed consent was obtained from all patients. A total of 144 patients had both a stenotic/occluded suitable (>1.5 mm) RV branch of the RCA and a stenotic/occluded distal RCA and underwent coronary artery bypass surgery between September 1, 2010, and September 30, 2020. Forty-four patients were excluded based on set criteria; thus, the final cohort number was 100. Data about RV function were collected prospectively from standardized transesophageal echocardiographic (TEE) and transthoracic (TTE) examinations in all patients. All patients had severe RCA stenosis, and the included patients were divided into 2 groups. Group 1 consisted of 50 patients who
had no additional bypass to the RV branch of the RCA. Group 1 patients had only a single distal bypass on the RCA. Group 2 comprised 50 patients who had an additional bypass on the RV branch of the RCA. Group 2 patients had 2 grafts on the RCA (one on the RV branch of the RCA and another on the distal part of the RCA).

Nineteen proximal anastomoses were performed on the ascending aorta separately (Fig. 1). Thirty-one proximal anastomoses of RV branch grafts were performed to the other RCA grafts in a “Y” fashion (Fig. 2). Radial artery grafts for branch bypass were used in 21 patients. To avoid disfiguration, a sequential anastomosis technique was not preferred. Patient characteristics are summarized in Table I.

Right coronary artery injection clearly reveals the coronary anatomy in many patients. If stenosis is seen in both the RCA and the RV branch, coronary surgery can be planned preoperatively. However, in cases of completely occluded RCA, the distal part of the RCA cannot be visualized unless it is filled with another injection. Fortunately, the distal RCA can be filled with left coronary artery injection. However, RV branch arteries cannot be visualized with left coronary artery injection. Therefore, the anatomy of the RV artery and the necessity of exploration during coronary surgery are not certain. This study proposed that if a good caliber branch artery is found during surgery that cannot be visualized both antegrade and retrograde in the preoperative period, it must be grafted.

**Inclusion Criteria**

In all patients ejection fraction (EF) was greater than 50%. Patients undergoing conversion, valve procedure, or repeat surgery were excluded from the study. All patients had RCA-dominant coronary anatomy and severe RCA stenosis. Patients with an RCA RV branch diameter of adequate size (≥1.5 mm) were included in group 2. Distal RCA branches were bypassed in group 2. Patients without an adequate-size RV branch were included in group 1. Distal anastomoses were performed either on

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**Fig. 1** Radial artery grafts were used for both the right ventricular branch (red arrow) and the distal right coronary artery (black arrow). Proximal anastomoses were done to the ascending aorta separately (surgical illustration).

**Fig. 2** Two different saphenous veins were anastomosed to both the right ventricular branch of the right coronary artery (red arrow) and the distal right coronary artery (black arrow). Proximal anastomosis of the distal right coronary artery graft was placed to ascending aorta. Proximal anastomosis of right ventricular branch graft was placed to other saphenous vein in end-to-side (“Y”) fashion (asterisk; surgical illustration).
the body of the RCA or on the posterior branches of the RCA in group 1. Patients with nonobstructed and RV branches of adequate size were excluded to avoid confounding results.

**Surgical Technique**

Standard anesthesia monitors supplemented with left radial arterial catheters and central venous or pulmonary artery catheters were used. A central venous catheter was commonly inserted into the jugular vein. Intravenous midazolam was administered for anxiolysis if needed. Propofol, etomidate, volatile anesthetic agents, sufentanil and/or fentanyl, and a depolarizing or nondepolarizing muscle relaxant were given for anesthesia induction and maintenance. Patients were routinely kept normothermic and in the supine position. The pump was ready but not primed. Medial sternotomy was performed to harvest the left internal thoracic artery (LITA) and right internal thoracic artery grafts. Both radial artery and saphenous vein grafts were used. Heparin (2 mg/kg) was administered before ligation of the distal part of the LITA, and the activated clotting time was maintained between 200 and 300 seconds during the operation. Epicardial stabilizers were routinely used for all anastomoses. The suction paddles were placed close to and parallel to the coronary artery to obtain maximum immobilization and minimum compromise of muscle function. Suction was activated in each paddle separately and fixed at the target site once suction was −400 mm Hg. The Octopus (Medtronic) vacuum stabilizer device was used during coronary anastomoses. The Starfish apical vacuum device (Medtronic) was routinely used for posterolateral and posterior descending coronary arteries. Coronary arteries were taped proximally and distally by silastic sutures. Coronary shunts were routinely used.

**TABLE I Preoperative and Postoperative Variables**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group 1</th>
<th>Group 2</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>n</strong></td>
<td>50</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td><strong>Preoperative variables</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female sex</td>
<td>17 (34)</td>
<td>15 (30)</td>
<td>.450</td>
</tr>
<tr>
<td>NYHA class I-IV, mean (SD)</td>
<td>2.01 (0.14)</td>
<td>2.17 (0.56)</td>
<td>.101</td>
</tr>
<tr>
<td>No. of vessels with disease, mean (SD)</td>
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<td>2.41 (0.32)</td>
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<td>LMCA</td>
<td>6 (12)</td>
<td>4 (8)</td>
<td>.774</td>
</tr>
<tr>
<td>Diabetes</td>
<td>17 (34)</td>
<td>15 (30)</td>
<td>.548</td>
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<tr>
<td>Hypertension</td>
<td>26 (52)</td>
<td>23 (46)</td>
<td>.671</td>
</tr>
<tr>
<td>COPD</td>
<td>11 (22)</td>
<td>9 (18)</td>
<td>.562</td>
</tr>
<tr>
<td>Preoperative MI</td>
<td>31 (62)</td>
<td>33 (66)</td>
<td>.101</td>
</tr>
<tr>
<td>Preoperative stroke</td>
<td>2 (4)</td>
<td>1 (2)</td>
<td>.999</td>
</tr>
<tr>
<td>PVD</td>
<td>7 (14)</td>
<td>11 (22)</td>
<td>.455</td>
</tr>
<tr>
<td><strong>Postoperative variables</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inotropic agent required</td>
<td>11 (22)</td>
<td>2 (4)</td>
<td>.013</td>
</tr>
<tr>
<td>No. of grafts, mean (SD)</td>
<td>3.15 (1.10)</td>
<td>3.74 (0.93)</td>
<td>.351</td>
</tr>
<tr>
<td>ICU stay, mean (SD), d</td>
<td>2.11 (1.12)</td>
<td>1.45 (0.71)</td>
<td>.033</td>
</tr>
<tr>
<td>Hospital stay, mean (SD), d</td>
<td>7.32 (1.44)</td>
<td>6.22 (0.45)</td>
<td>.027</td>
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<td><strong>Types of graft</strong></td>
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<td></td>
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<tr>
<td>LITA</td>
<td>46 (92)</td>
<td>47 (94)</td>
<td>.944</td>
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<tr>
<td>Radial artery</td>
<td>31 (62)</td>
<td>27 (54)</td>
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<td>Saphenous vein</td>
<td>50 (100)</td>
<td>50 (100)</td>
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<td>Perioperative MI</td>
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<tr>
<td>New renal failure</td>
<td>1 (2)</td>
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<td>.999</td>
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<tr>
<td>Postoperative atrial fibrillation</td>
<td>21 (42)</td>
<td>14 (28)</td>
<td>.044</td>
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<tr>
<td>1-y mortality</td>
<td>-</td>
<td>-</td>
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</tr>
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</table>

COPD, chronic obstructive pulmonary disease; ICU, intensive care unit; LITA, left internal thoracic artery; LMCA, left main coronary artery; MI, myocardial infarction; NYHA, New York Heart Association

*Data are expressed as No. (%), unless otherwise stated. P < .05 is considered significant.*
after distal anastomosis. Then, the circumflex (Cx) region and diagonal anastomoses were done. Left internal thoracic artery to left anterior descending artery anastomosis was done after the Cx region and diagonal arteries were bypassed. The LITA to left anterior descending anastomosis was done last to avoid stretching the LITA during the left-side coronary anastomosis. Graft blood flow rates (in mL/min) were measured using Doppler ultrasound after all anastomoses were completed and protamine was administered.

**Echocardiographic Examination**

Right ventricle output measurements by thermodilution catheters, cardiac magnetic resonance imaging, and radionuclide studies are being used for RV function. However, these studies are expensive and impractical. Echocardiographic evaluation for RV function is simple, inexpensive, and practical. Recently developed echocardiographic criteria, such as transannular plane systolic excursion (TAPSE), fractional area change (FAC [%]), RV S′-wave velocity, and inferior vena cava (IVC) measurements safely show RV function. These 4 criteria were used in this study. Several studies have been published on TAPSE and FAC for RV function determination. Speckle tracking echocardiography (STE) is also useful for distorted RV geometry after CABG, but STE is expensive and requires more experience than does echocardiographic evaluation.

**Echocardiographic Parameters**

Transannular plane systolic excursion was obtained in an apical 4-chamber view with the M-mode cursor placed through the lateral tricuspid annulus at the junction of the tricuspid valve plane with the free wall of the RV (<16 mm indicates RV systolic dysfunction). Fractional area change is another RV performance parameter and measured by the following equation (<35% indicates RV systolic dysfunction): [FAC = end-diastolic area – end systolic area / end-diastolic area × 100].

Among the most reliably and reproducibly imaged regions of the RV are the tricuspid annulus and the basal free wall segment. These regions can be assessed by pulsed-tissue Doppler and color-coded–tissue Doppler imaging to measure the longitudinal velocity of excursion. This velocity has been termed the Rs′ or systolic excursion velocity. To perform this measure, an apical 4-chamber window is used with a tissue Doppler mode region of interest highlighting the RV free wall. The pulsed Doppler sample volume is placed in either the tricuspid annulus or the middle of the basal segment of the RV free wall. The mean value of Rs′ is approximately 15 cm/s, and the lower reference limit is 10 cm/s.

The subcostal view is the most useful view to assess the IVC, with the IVC viewed in its long axis. The measurement of IVC diameter should be made at end expiration and just proximal to the junction of the hepatic veins that lie approximately 0.5 to 3.0 cm proximal to the ostium of the right atrium (RA). The diameter of the IVC is reflected by RA pressure. Collapsing of IVC diameters with a sniff is also important. An IVC diameter less than 21 mm and IVC collapse of more than 50% during sniff denotes normal RA pressure (0-5 mm Hg). An IVC diameter greater than 21 mm and IVC collapse less than 50% during sniff denotes normal high RA pressure (>15 mm Hg).4

**Timing of Echocardiographic Examination**

All patients received a standardized echocardiographic (TEE and TTE) examination performed prospectively. Vivid E9 (GE Healthcare) consoles were used to examine RV function. A midesophageal 4-chamber view centered on the RV was obtained and recorded at the intraoperative time period. Measurements were done preoperatively and intraoperatively 30 minutes after protamine administration (TEE examination). Transthoracic echocardiographic examinations were done preoperatively and then postoperatively at 7, 30, and 90 days. All examinations were performed in the supine position with a transthoracic ultrasound device equipped with a phase-array transducer of 2.5 MHz.

**Postoperative Angiographic Studies**

Angiographic studies were carried out in all study groups at 1 year postoperatively.

**Statistical Analysis**

Statistical analysis was performed with SPSS software, version 19 (IBM). Continuous variables were expressed as mean (SD), and categorical variables were represented by frequency and percentage. Categorical variables were assessed using the chi-square and Fisher exact tests. Continuous variables were compared using the unpaired Student t test or Mann–Whitney U test. For all comparisons, P < .05 was considered statistically significant.

**Results**

There was no mortality in the first postoperative year. Graft occlusion on the right side was observed in 5 RCA distally bypassed grafts, whereas all grafts on the RV branch of RCA were patent. Four of the grafts had occluded in group 1 patients, and 1 of the grafts had occluded in a group 2 patient. All occluded grafts were compared with preoperative images, and occlusions could be explained by poor distal runoff. Postoperative atrial fibrillation developed in 21 patients in group 1 and 14 patients in group 2 (P = .044). Use of inotropic agents was required in 11 patients in group 1 and 2 patients in group 2 (P = .013). The mean (SD) intensive care unit stay was 2.11 (1.12) days in group 1 and 1.45
Postoperative 7 d

This decline in RV function is attributable to events that are mainly associated with CPB or cardioplegic arrest and, further, are likely to be related to ischemia-reperfusion injury, the effects of the type or temperature of cardioplegia solution, or the method and route of cardioplegia delivery. Pericardiectomy may also be a factor for reduction of RV function. Singh et al showed that changes in RV function in patients having complete pericardiectomy and full sternotomy were similar to those having a limited pericardiectomy via a right thoracotomy, providing evidence to suggest that a pericadiectomy incision does not affect RV longitudinal function. Mechanical factors such as inadequate cooling of the RV during surgery, RCA air embolization during open heart surgery, and inadequate protection of the RV during coronary surgery have been postulated.

Discussion

Previous studies have demonstrated that the most significant decline in RV function occurred immediately following separation from CPB and continued to the end of surgery. This decline in RV function is attributed to...
astolic pressure as measured indirectly by pulmonary artery diastolic pressure and by pulmonary capillary wedge pressure and a significant increase in mean (SD) cardiac index to 3.2 (0.9) L/min/m². Güney and Eren advocate that complete revascularization of extended RCAs did not seem advantageous over conventional operation in patients with normal ventricular function. However, in patients with poor ventricular function (EF <50%), grafting of RV branches prevented perioperative ischemic events in the right coronary territory and the consequent functional impairment that appeared with conventional operation. The team changed its RCA revascularization procedure in 2010, and all graftable RV branches of the RCA have been bypassed since. Many surgeons have experienced that the available RCA may not be found in the distal part of the RCA. The posterior descending branch of the RCA is mainly bypassed in such instances. But, available posterior descending arteries may not be always found, and this may increase mortality and cause postoperative chest pain. A graftable RV branch of the RCA was searched, and if a good branch was found, it was bypassed. It was observed that the RV branch of the RCA was exceptionally free of atherosclerosis after the first 15 to 20 mm arising from RCA. This feature may increase the patency of grafts. All of the branch grafts were shown to be patent angiographically at 1 year postoperatively. Good runoff, relatively short graft, and both systolic and diastolic flow on branch arteries may be reasons for a good patency rate. It was found that even a single RV branch of RCA grafting has a high patency rate. Several studies denote systolic RV dysfunction after CABG. Ozerdem et al demonstrated that diastolic function is also adversely affected in the postoperative period after classical bypass grafting. They have also sequentially grafted both distal RCA and RV branches, and they noticed that RV diastolic functions were improved in postoperative echocardiographic studies. Noninvasive evaluation of RV function can be done safely via recently developed echocardiographic examinations. Transannular plane systolic excursion is frequently measured for evaluation of RV function. Modin et al advocate that TAPSE can accurately be used for RV systolic function and may provide novel prognostic information about the risk of cardiovascular disease. Fractional area change and RvS were also used in determining RV function noninvasively. All 3 parameters in 5 different time periods were used. We have also found RV systolic dysfunction after off-pump coronary bypass surgery. Khani et al reported that reduction in TAPSE may be seen after off-pump surgery. The etiology of RV dysfunction is not very clear, but it is likely to be ischemic in nature. Farrar et al pointed out that RV contractility is essential for a sufficient RV blood flow and prevention of RV dysfunction. Main research topics in this area have focused on methods to supply adequate intraoperative protection of RV myocardium. Mullen et al compared the effects of blood vs crystalloid cardioplegia on RV dysfunction. Their results showed that crystalloid cardioplegia resulted in lower RV temperatures and improved RV systolic function. This means that lower RV temperatures are a primary protective mechanism against RV dysfunction. However, this team does not agree with this idea. Right coronary arteries commonly have multiple stenosis, and single bypass to any part of the RCA may lead to incomplete myocardial protection. A major determinant in the prevention of RV dysfunction is complete revascularization of the RCA with particular attention to the RV branch of the RCA when stenosis exists. Multiple bypasses on the RCA may reduce postoperative RV failure incidence in on-pump and cross-clamping coronary surgery. Olearchyk has shown numerous favorable results of branch bypass, such as reduced postoperative RA pressure and pulmonary artery systolic, diastolic, and pulmonary capillary wedge pressure. Olearchyk has also shown that reduced left ventricular end-diastolic pressure, and increased cardiac index by using additional graft to RV branch. Fortunately, RV systolic dysfunction after successful cardiac surgery is recovered in the postoperative 1 to 12 months. But persistent RV systolic dysfunction may have a negative effect on long-term survival. Bootsma et al have measured right ventricular ejection fraction (RVEF) using a thermodilution catheter and categorized persistent RV dysfunction after cardiac surgery into 3 groups. They found that 2-year mortality was significantly different across groups, at 4.1% for patients with an RVEF greater than 30%, 8.2% in the group with an RVEF of 20% to 30%, and 16.7% for patients with an RVEF less than 20%. Poor distal runoff is the most important predictor of graft patency. Graft flow is also dependent on distal runoff. Four single grafts on the RCA system occluded in group 1 patients because of poor runoff. Reduced flow on the graft may cause early graft occlusion. Additional grafts to the RV branch on the RCA may increase graft flow and velocity in a Y-type graft configuration, and this may also reduce the risk of graft occlusion. The occluded graft in group 2 was done as an individual graft on the distal right coronary system. The RV branch graft was patent in that patient.

**Study Limitations**

This was not a randomized study. The groups were not matched in any way before surgery but were selected at operation based on the size of the RV branch artery to be bypassed. The results of the study may have been influenced by subtle variables such as the extent of disease in the RCA. Selection bias may have influenced our results.
Conclusion

This study was designed to eliminate CPB and myocardial protection as factors for RV ventricle dysfunction. The team performed multiple bypasses in group 2 patients via off-pump surgery. It was attempted to bypass all available RV branch vessels additional to the distal RCA system. It was found that RV branch vessel (including conus, marginal, and any good runoff vessels on the RV) grafting alleviates and provides rapid recovery of RV dysfunction. Speckle tracking echocardiography is useful for distorted RV geometry after CABG. The team hopes that well-designed prospective randomized studies with large sample sizes and STE used for the TAPSE variable might verify the conclusions made.

Published:
Conflict of Interest Disclosure: None
Funding/Support: None

References
QUERIES
AU: GLOBAL QUERY: Should “Doppler S-wave velocity” be edited to “Doppler S′-wave velocity” throughout?
AU: GLOBAL: Should any diacritical marks be added to author or other names in the manuscript? A Google search shows them with some names (eg, Yokusoglu being Yokuşoğlu)
AU: In the keywords section, MeSH has “off pump, coronary artery bypass” or “coronary artery bypass off pump.” Which would you like to change “off pump” to?
AU: In the Abstract, should “Inotropy” be “Positive inotropy” or “Inotropic agents”? Also, note that the abstract should be 250 words or less, so we added abbreviations (not usually per style) and some edits to reduce the number of words. Please review.
AU: In the Patients and Methods section, please confirm or correct specific date range: “September 1, 2010, to September 30, 2020”
AU: In the Surgical Technique section, please confirm edit to “Propofol, etomidate, volatile anesthetic agents, sufentanil and/or fentanyl, and a depolarizing or non-depolarizing muscle relaxant were given for anesthesia induction and maintenance”
AU: In the Surgical Technique section, please review the following: “Left internal thoracic artery to left anterior descending artery anastomosis was done after the Cx region, diagonal arteries were bypassed”---should this be “Left internal thoracic artery to left anterior descending artery anastomosis was done after the Cx region, and diagonal arteries were bypassed”?
AU: In the Surgical Technique section in the sentence beginning “The suction paddles,” which coronary artery is referred to by “the coronary artery”?
AU: Please confirm values for LVEF in Table II. Is it OK that means and SDs are expressed to different decimal places?
AU: In the Echocardiographic Examination section, please provide any relevant citations for “Several studies have been published on TAPSE and FAC for RV function determination”.
AU: In Echocardiographic Parameters, should “An IVC diameter less than 21 mm and IVC collapse of more than 50% during sniff denotes normal right atrial pressure (0-5 mm Hg). An IVC diameter greater than 21 mm and IVC collapse less than 50% during sniff denotes normal high RA pressure (>15 mm Hg).” be “An IVC diameter greater than 21 mm and IVC collapse less than 50% during sniff denotes normal to high RA pressure (>15 mm Hg).”
AU: In the Statistical analysis section, “or median with interquartile range” was deleted because no median (IQR) values appear in the manuscript. Please review if those values are missing and should be present.
AU: In the Results section, please review “A single patient in group 1 died at the end of the first postoperative year.”---Per Table I, no results are reported for “1-year mortality”---should data in either location be edited?
AU: In Table I, should the number for “New renal failure” in group 2 be zero? If not, please indicate the meaning of the dash. (Please also address the issue with 1-year mortality mentioned above).