Impact of purely internal thoracic artery T-graft technique on the mode and quality of surgical myocardial revascularization evaluated by early postoperative coronary angiography

Impact de l’utilisation exclusive des artères thoraciques internes montées en T sur le mode et la qualité de la revascularisation coronaire chirurgicale évaluée par coronarographie postopératoire précoce

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KEYWORDS
Arterial grafts; Coronary artery bypass graft; Coronary artery imaging

Summary
Background. — The use of the internal thoracic artery for coronary artery bypass has improved the results of such surgery. However, bypass using only the internal thoracic arteries sometimes requires a T-graft. This purely internal thoracic artery T-graft technique has progressively become part of our surgical protocol for coronary artery bypass surgery.
Aims. — The aim of the study was to analyse the impact of this surgical technique on the degree and quality of coronary revascularization using early postoperative angiography.
Methods. — Between January 2004 and December 2006, 148 patients underwent coronary bypass surgery exclusively using both internal thoracic arteries in a T-graft configuration. Systematic postoperative angiography was offered to all 148 patients; it was accepted by 108 patients and refused by 40 patients.
Results. — There were no statistically significant differences between the two groups. Inpatient mortality was 2.02% (n = 3) for the whole population studied, and 1.49% (n = 2) for the 134 patients who received only coronary artery bypass grafts. The revascularization rate was

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89% and 3.46 coronary anastomoses were constructed per patient (range 2—6). Angiography was performed on 108 right internal thoracic artery to left internal thoracic artery anastomoses, 374 anastomoses of internal thoracic arteries to coronary arteries and 382 inter-anastomosis segments: 98% of the anastomoses and segments were patent.

**Conclusion.** — The exclusive recourse to the purely internal thoracic artery T-graft technique meant that it has been possible to dispense with other types of graft while achieving complete and effective revascularization of the coronary artery.

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**Résumé**

**Introduction.** — L'utilisation de l’artère thoracique interne pour la revascularisation coronaire chirurgicale a permis d’améliorer les résultats de cette chirurgie. Mais la revascularisation exclusive avec ces artères impose parfois le recours à la technique du montage en T. Cette technique a progressivement été intégrée dans notre activité de revascularisation coronaire chirurgicale.

**Objectifs.** — L’étude vise à analyser l’impact de cette technique chirurgicale sur le mode et la qualité de la revascularisation coronaire par un contrôle angiographique postopératoire précoce.

**Méthode.** — Entre janvier 2004 et décembre 2006, 148 patients ont bénéficié d’une revascularisation coronaire chirurgicale en utilisant exclusivement les deux artères thoraciques internes par la technique du montage en T. La coronarographie postopératoire systématiquement proposée aux 148 patients a été acceptée par 108 patients (groupe Angio+) et refusée par 40 patients (groupe Angio—). Il n’existait aucune différence statistiquement significative entre les deux groupes.

**Résultats.** — La mortalité hospitalière était de 2,02% (trois décès) pour toute la population étudiée, et de 1,49% (deux décès) pour les 134 patients opérés de pontages coronaires isolés. Le taux de revascularisation était de 89%. 3,46 anastomoses coronaires par patient (deux à six) ont été réalisées et l’analyse angiographique a porté sur 108 anastomoses de l’artère thoracique interne droite sur l’artère thoracique interne gauche, 374 anastomoses d’artère thoracique interne sur des artères coronaires, et 382 segments interanastomotiques. Quatre-vingt-dix-huit pour cent des anastomoses et segments étaient fonctionnels.

**Conclusion.** — Le recours à la technique du montage en T exclusivement avec les artères thoraciques internes a permis de se dispenser de tout autre greffon tout en réalisant une revascularisation coronaire chirurgicale complète et fonctionnelle.

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**Abbreviations**

BITA Bilateral internal thoracic artery
ITA Internal thoracic artery
LAD Left anterior descending
LITA Left internal thoracic artery
LPD Left posterior descending
RITA Right internal thoracic artery

**Background**

The ITA is the gold standard for surgical revascularization of the LAD artery because of its functional effectiveness and the postoperative clinical benefits [1,2]. Postoperative clinical benefits are also improved if both ITAs (BITA) are used for coronary artery bypasses in cases of multivessel disease [3—7]. However, the anatomical constraints of the in situ ITA generally mean that other grafts are required to complete the revascularization for multivessel coronary disease and for coronary arteries that are difficult to access in posterolateral or inferior regions. The BITA T-graft technique reported previously [8] is appealing because it permits BITA revascularization without recourse to other grafts. This technique has been adopted by our team for patients in whom the in situ ITA did not provide the required revascularization. However, certain questions regarding this technique (the possibility of accessing all the coronary arteries by the T-graft without restriction; the possibility of myocardial revascularization using this T-graft technique with specific features [common LITA vessel, kissing anastomoses]) led us to perform early postoperative angiographic monitoring from the time when we began using the technique.

We report here the results of this analysis in terms of the mode and quality of surgical coronary artery revascularization with this still little-used surgical technique.

**Methods**

Between January 2004 and December 2006, 148 patients received coronary artery bypass grafts according to the T-graft technique using both ITAs; all operations were performed by the same surgeon (DC). Cardiopulmonary bypass surgery was performed under strict normothermia with warm blood cardioplegia by repeat anterograde injections...
between the constructions of each distal coronary anastomosis.

The graft technique was performed with the RITA used as a free graft reimplanted on the LITA. Each branch of the T-graft bypassed one coronary artery (via an end-to-side anastomosis) or several coronary arteries (via an end-to-side and one or several side-to-side anastomoses), thus achieving sequential coronary artery bypasses. Aortic valves were replaced during the same intervention in 14 of these patients.

Early postoperative monitoring angiography (within eight days postoperatively) was proposed systematically for the first patients receiving a T-graft (during the initial period of our experience with this technique). All patients were given detailed information regarding the aims and modalities of this angiographic monitoring. The postoperative coronary angiogram was accepted by 108 patients and 40 patients refused. Coronary angiograms were performed via the left radial artery with injections into the LITA, combined with opacification of the native coronary arteries when opacification of the LITA was considered by the operator to be unsatisfactory. The results of these examinations were confirmed by double reading of the angiograms, firstly by the initial angiographer and the surgeon, then by another coronary angiographer.

A scheme was designed to standardize the reading of the coronary angiograms (Fig. 1). The native coronary arteries were divided into three groups: LAD artery and diagonal artery network; circumflex artery and obtuse marginal artery network; right coronary artery and LPD artery and posterior obtuse marginal artery.

The coronary bypasses were characterized by anastomoses (even numbers), each including the anastomosis itself and also the 5 mm upstream and downstream and the segments (uneven numbers) between the anastomoses (Fig. 1).

Functional state was evaluated for each anastomosed site and each segment, and expressed according to the following criteria: occlusion when there was sudden and enduring arrest of contrast medium; stenosis when there was a greater than 50% reduction in calibre; non-significant stenosis when there was a lower than 50% reduction in calibre; competitive flow when there was arrest of the contrast medium with some forward and backward flow; normal when there were no morphological abnormalities and no abnormal flow of the contrast medium.

The revascularization ratio was calculated by relating the number of coronary arteries that were revascularized effectively to the number of coronary arteries judged to require revascularization on the basis of the preoperative coronary angiography.

Statistical analyses were performed using the Chi² test when the sample population was greater than five and Fisher’s test in other situations. Data were compared using analysis of variance and means were compared by Student’s t test. Differences were considered to be significant when \( p < 0.05 \). Statistical calculations were performed with the Epi info® software.

Results

Table 1 shows the individual and surgical characteristics of the 148 patients operated on over the period during which monitoring angiography was proposed systematically (2004–2006). These characteristics are shown separately for the two groups, i.e. the group of 108 patients who accepted angiography (Angio+) and the 40 patients who refused (Angio−). No statistically significant differences were observed between the two groups.

Three patients died before discharge (in-hospital mortality was 2.02%): one of septicemia after gastrointestinal ischemia and two of cardiac failure, one of which was related to a less than 30% preoperative left ventricular ejection fraction and the other to associated valvular cardiopathy. Of the 134 patients in the group operated on exclusively for coronary revascularization, two patients (1.4%) died before discharge. No cases of mediastinitis occurred in this group of patients. The anatomical distribution of the coronary arteries revascularized by a T-graft is shown in Fig. 2.

The level of coronary revascularization achieved following surgery was 89%, and the levels of revascularization achieved surgically for each of the three coronary areas defined above were 85% for the LAD-diagonal artery network, 92% for the circumflex artery network and 90% for the right coronary artery network. The lower level of revascularization achieved in the LAD-diagonal artery region network compared with the levels in the other regions’ networks can be explained by the low level of revascularization of the diagonal arteries that were often judged by the surgeon to be very thin and thus often left, whereas 99% (147/148) of the LAD arteries were revascularized. Revascularization was possible for nine out of ten diseased coronary arteries because of the anatomical configuration of the T-graft,

![Figure 1](image-url)
which made it possible to apply the ITA to any coronary artery, as illustrated in Fig. 3.

This revascularization was achieved by means of the progressive increase in the number of coronary arteries revascularized by a surgical procedure (Fig. 4) and the progressive increase over time in the number of T-grafts performed (20% of bypasses in 2004, 35% in 2005 and 63% in 2006). The combination of these two factors made it possible to increase the number of bypasses per patient and to reduce recourse to venous or arterial grafts other than the ITA. The number of arteries revascularized using venous grafts was 17% in 2004, 9% in 2005 and 7% in 2006.

The functional status of coronary artery bypasses as demonstrated by angiography is summarized in Table 2. Ninety-eight percent of anastomoses and segments were effective (i.e., not occluded or without significant stenosis). Thus, 87% of diseased coronary arteries requiring a bypass were effectively (89% revascularization) and efficiently (98% patent) revascularized.

### Table 1. Patient characteristics ($n=148$).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Angio+</th>
<th>Angio−</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>EuroScore</td>
<td>2.5</td>
<td>2.3</td>
<td>0.38</td>
</tr>
<tr>
<td>Age (years)</td>
<td>64.9</td>
<td>63.6</td>
<td>0.62</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>27.7</td>
<td>28.1</td>
<td>0.56</td>
</tr>
<tr>
<td>Left ventricular ejection fraction (%)</td>
<td>56.4</td>
<td>60.0</td>
<td>0.11</td>
</tr>
<tr>
<td>Cardiopulmonary bypass time (min)</td>
<td>78.1</td>
<td>79.0</td>
<td>0.40</td>
</tr>
<tr>
<td>Aortic cross-clamp time (min)</td>
<td>59.1</td>
<td>58.2</td>
<td>0.15</td>
</tr>
<tr>
<td>Assistance time (min)</td>
<td>8.0</td>
<td>9.8</td>
<td>0.69</td>
</tr>
<tr>
<td>Number of anastomoses/LITA</td>
<td>1.2</td>
<td>1.2</td>
<td>0.85</td>
</tr>
<tr>
<td>Number of anastomoses/RITA</td>
<td>2.1</td>
<td>2.2</td>
<td>0.31</td>
</tr>
<tr>
<td>Blood loss (mL)</td>
<td>636.9</td>
<td>541.3</td>
<td>0.18</td>
</tr>
<tr>
<td>Interval to discharge (days)</td>
<td>10.8</td>
<td>11.4</td>
<td>0.49</td>
</tr>
<tr>
<td>Postoperative complication ratio</td>
<td>8 (7.4%)</td>
<td>6 (15.0%)</td>
<td>NS</td>
</tr>
<tr>
<td>Female sex-ratio</td>
<td>10 (9.3%)</td>
<td>3 (7.5%)</td>
<td>NS</td>
</tr>
<tr>
<td>Type 1 diabetes ratio</td>
<td>4 (3.7%)</td>
<td>1 (2.5%)</td>
<td>NS</td>
</tr>
<tr>
<td>Type 2 diabetes ratio</td>
<td>26 (24.0%)</td>
<td>7 (17.5%)</td>
<td>NS</td>
</tr>
</tbody>
</table>

Values given as means unless otherwise stated.

LITA: left internal thoracic artery; NS: not significant; RITA: right internal thoracic artery.

Figure 2. Distribution of coronary arteries revascularized by T-graft and monitored by angiogram.
LAD: left anterior descending artery; LPD: left posterior descending artery; OM 1: obtuse marginal artery 1; OM 2: obtuse marginal artery 2; PM: posterior marginal artery.

Figure 3. Example of full coronary revascularization by T-graft; the numbers define the anastomoses according the diagram shown in Fig. 1.
LITA: left internal thoracic artery; RITA: right internal thoracic artery.
Figure 4. Evolution of number of coronary arteries treated by bypass surgery involving the T-graft technique. ITA: internal thoracic artery; LITA: left internal thoracic artery; RITA: right internal thoracic artery.

<table>
<thead>
<tr>
<th>No.</th>
<th>Number of patients</th>
<th>n (%)</th>
<th>Normal</th>
<th>Stenosis &lt; 50%</th>
<th>Competitive flow</th>
<th>Stenosis &gt; 50%</th>
<th>Occlusion</th>
</tr>
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<tbody>
<tr>
<td>Overall</td>
<td>966</td>
<td>908 (94)</td>
<td>20 (2.1)</td>
<td>18 (1.9)</td>
<td>6 (0.6)</td>
<td>14 (1.4)</td>
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<tr>
<td>Left anterior descending artery network</td>
<td></td>
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<tr>
<td>1</td>
<td>108</td>
<td>107 (99.1)</td>
<td>1 (0.9)</td>
<td>—</td>
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<td>—</td>
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<tr>
<td>2</td>
<td>108</td>
<td>104 (96.2)</td>
<td>2 (1.8)</td>
<td>—</td>
<td>2 (1.8)</td>
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<tr>
<td>3</td>
<td>108</td>
<td>106 (98.2)</td>
<td>2 (1.8)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td></td>
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<tr>
<td>4</td>
<td>38</td>
<td>35 (92.2)</td>
<td>1 (2.6)</td>
<td>1 (2.6)</td>
<td>—</td>
<td>1 (2.6)</td>
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<tr>
<td>5</td>
<td>37</td>
<td>35 (94.6)</td>
<td>1 (2.7)</td>
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<td>1 (2.7)</td>
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<tr>
<td>6</td>
<td>107</td>
<td>90 (84.1)</td>
<td>4 (3.7)</td>
<td>10 (9.4)</td>
<td>—</td>
<td>3 (2.8)</td>
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<tr>
<td>Circumflex artery network</td>
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<td>7</td>
<td>108</td>
<td>103 (95.4)</td>
<td>4 (3.7)</td>
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<td>1 (0.9)</td>
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<td>8</td>
<td>91</td>
<td>85 (93.4)</td>
<td>3 (3.3)</td>
<td>1 (1.1)</td>
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<td>2 (2.2)</td>
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<tr>
<td>9</td>
<td>76</td>
<td>75 (98.7)</td>
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<td>1 (1.3)</td>
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<tr>
<td>12</td>
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<td>Right coronary artery network</td>
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<tr>
<td>15</td>
<td>1</td>
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<tr>
<td>16</td>
<td>36</td>
<td>33 (91.6)</td>
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<td>18</td>
<td>64</td>
<td>52 (81.2)</td>
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<td>5 (7.8)</td>
<td>1 (1.6)</td>
<td>5 (7.8)</td>
<td></td>
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</tbody>
</table>
Discussion

ITAs are accepted as excellent grafts for coronary bypass surgery in terms of patency, effectiveness and clinical benefit, whether performed using one ITA [2] or —to an even greater extent— both ITAs [6].

The strategy of using only the ITA for coronary bypass surgery is based on several factors. Increasing the number of coronary arteries revascularized by ITA increases the clinical benefits of bypass surgery; there is a reduction in recourse to venous grafts that have low functional durability and hence, fewer clinical benefits long-term. The ITA is a more active graft than other grafts (venous, radial artery), in terms of endothelial mediators such as nitric oxide, prosta-cycline, etc. [9—13] (the mediators thus produced confer resistance to vascular thrombosis, resistance to progression of atheroma and functional improvement of the microcirculation—all factors that are propitious for conservation of the myocardial capital); the greater the number of coronary arteries revascularized by the ITA, the greater the myocardial region benefitting from the biochemical advantages of these mediators and the greater the long-term myocardial protection—as a consequence, this reduces the number of surgical accesses per patient because a single sternotomy can be used to take the vessel grafts and to construct the vascular anastomoses. Surgical accesses only for the purpose of taking the vessel grafts, whether they are internal saphenous veins or radial arteries, can be avoided. Local complications of such surgical accesses are thus avoided, as are the discussions regarding open surgery or endoscopy to take the vessel grafts. Moreover, systematic use of BITA grafts does not increase the occurrence of mediastinitis, which is a severe complication of BITA removal. Mediastinitis did not occur in any of the patients operated on using the T-graft technique in this series.

The anatomical constraints of pedicled ITA grafts did not allow the revascularization of certain coronary arteries (lower obtuse marginal arteries, LPD artery) and necessitated recourse to supplementary grafts to complete the coronary revascularization. The T-graft technique resolved this problem using specific surgical approaches (LITA-RITA anastomosis, kissing anastomoses). It seemed to us that the quality of the coronary revascularization using these specific techniques needed to be evaluated. Early postoperative monitoring by angiography was the only reliable paraclinical means of investigation available to our team. The patients monitored were volunteers and were not patients selected for monitoring by angiography, which was proposed systematically for all patients undergoing T-grafting. Verification of the absence of statistically significant differences between the Angio+ and Angio— groups was a requirement to ensure the absence of bias in the expression of the results of such monitoring.

As the surgical experience with this technique progressed, the coronary revascularization ratio per patient increased because of the more frequent recourse to the T-graft technique and the increased numbers of anastomoses per surgical procedure. Selection of this technique by our team increased because it was recognized that all of the coronary arteries could be treated using this approach, including branches of the right coronary artery, which showed that both ITAs were appropriate for the treatment of diseased coronary arteries (Fig. 3). The number of anastomoses per procedure increased because of the freedom to revascularize any coronary artery due to the anatomical availability of the T-graft technique, particularly the right branch of the T-graft (RITA) parallel to the left atrioventricular groove and hence perpendicular to all the obtuse marginal arteries, the posterior marginal artery and the LPD artery, thus permitting kissing anastomoses of the RITA (diamond shaped) on the coronary arteries. The choice of revascularizing any particular coronary artery no longer required prior determination of the number of grafts to be taken for the planned revascularization, but depended only on the condition of the diseased coronary arteries requiring revascularization (calibre, state of coronary artery walls). Revascularization became more and more complete and recourse to supplementary grafts (from the internal saphenous vein) was only necessary when there were contraindications for using both ITAs (chronic obstructive pulmonary disease) and in cases where it was impossible to use the ITA (history of massive chest irradiation, fracture of the sternum, etc.).

The functional state of these T-grafts appeared to be satisfactory, as only 2% of the anastomoses and segments analysed were not patent (occluded or > 50% stenosed). Almost all the abnormalities observed involved the anastomosis sites, whereas almost all the segments between the anastomoses were normal. Thus, an occluded anastomosis did not affect the quality of the downstream segments. Anastomosis on the LPD artery (segment 18) was the segment with the highest level of occlusion (7.8%). In addition, there was 1.9% competitive flow in this series (from 0—9.4%, according to segment). Competitive flow involved the segments of revascularization of the LPD artery (segment 18), similar to the results published by Azmoun et al. [14] using the same T-graft technique, and also the revascularized LAD artery segments (segment 6), with competitive flows of 7.8% and 9.4%, respectively. The anastomoses and/or segments presenting competitive flow were considered to be patent as there was still downstream flow in the coronary network. In addition, the impact of the existence of competitive flow on the outcome of a bypass remains debatable [15—17]. The latter studies reported that a small degree of stenosis of the native vessel is correlated with a risk of occlusion of the bypass in time. However, other factors may influence the outcome of bypasses (degree of stenosis of the diseased coronary vessel, existence of collaterals in the native network, downstream quality of the revascularized vessel, etc.). The impact of flow deemed ‘competitive’ should not be analysed only in terms of the outcome of the bypass but also in terms of the outcome of the coronary flow, and consequently of residual or recurrent myocardial ischemia. The impact of competitive flow in our study was moderate in the early postoperative period as no early additional revascularization was required in the group of patients studied. These results are in agreement with those studies that have demonstrated that the flow reserve of T-grafts is sufficient for coronary revascularization [18, 19] and that multiple kissing anastomoses do not affect the quality of the revascularization [20]. The middle- and long-term clinical impact should be the subject of further study, particularly as there was more competitive flow in the LAD artery anastomosis, the most important factor for the patient’s prognosis.
The study presented here has demonstrated the rapid and progressive adoption of a surgical coronary bypass technique using the ITA exclusively, because of the early technical and clinical postoperative advantages, i.e. an increase in the levels of revascularization per patient and the early acceptable postoperative effectiveness of this revascularization technique regardless of the myocardial region revascularized. This surgical strategy was not burdened with untoward clinical outcomes, in terms of early postoperative mortality, infections or perioperative myocardial disease. Because of such an early postoperative clinical course, no additional revascularization process was performed for these 148 patients, including the two patients who had a stenosed LITA-RITA anastomosis (No. 2 anastomosis in Fig. 1). The angiographic aspects of these two stenoses were compatible with ITA wall haematoma. The absence of clinical impact and the potential for resorption of such haematomas allowed medical surveillance without any other therapeutic process.

Further studies are planned to measure the durability of the functional properties of this surgical bypass technique and the impact in terms of clinical benefit in the middle- and long-term.

**Conclusion**

The strategy of coronary bypass surgery using only the ITA, demonstrating almost complete and effective revascularization of the coronary network and including recourse to T-grafts when necessary, has become the current practice of our team of surgeons and is recommended by the authors.

**Conflict of interest**

None.

**References**


