Spinal cord ischemia after elective endovascular stent-graft repair of the thoracic aorta

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Abstract

Background: We reviewed our experience to investigate the determinants of paraplegia/paraparesis after endovascular stent-graft repair of the thoracic aorta, to assess the influence of the artery of Adamkiewicz (ARM) detected by preoperative magnetic resonance angiography (MRA) and to identify patients at risk.

Methods: Over a 5-year period (March 2001—June 2006), 149 patients underwent elective endovascular stent-graft repair of the descending thoracic aorta. Patient demographics and perioperative factors relating to the endovascular procedure were evaluated by using univariate statistical analyses. To assess the influence of the ARM in the thoracolumbar region, patients in whom ARM was detected by preoperative MRA were divided into two groups: patients who had occlusion of the intercostal artery for ARM due to stent-graft (group A, n = 33) and patients who had patency of the intercostal artery for ARM following stent-graft (group B, n = 38).

Results: Five (3.6%) of the 144 patients had paraparesis/paraplegia. Two of these five patients had previously undergone operation for total arch replacement with elephant trunk and one had surgery for descending aortic repair. Univariate analyses identified only prior aortic surgery as a significant risk factor (p = 0.04). Paraparesis/paraplegia rates were 10% (three patients) in group A and 0% in group B (p = 0.09).

Conclusion: Prior thoracic aortic replacement was found to be a significant predictor of spinal cord ischemia, and therefore vigilance is needed regarding occlusion of the intercostal artery for ARM detected prior to stent-graft repair.

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Keywords: Paraplegia; Spinal cord ischemia; The artery of Adamkiewicz (ARM); Thoracic aortic aneurysm

1. Introduction

Postoperative paraplegia or paraparesis is a serious complication of reconstructive surgery of the thoracoabdominal or descending aorta, the major cause of which is thought to be spinal cord ischemia during and after the procedure. In our institute, we have routinely reconstructed or preserved an intercostal artery that may be related to the artery of Adamkiewicz (arteria radicularis magna: ARM) preoperatively detected by magnetic resonance angiography (MRA) during operations for repair of thoracoabdominal or descending thoracic aortic aneurysm (TAA) [1].

Published reports of endovascular thoracic aortic repair are limited, but spinal cord ischemia has been noted. Greenberg et al.’s report of neurologic deficit due to spinal cord ischemia in 3 out of 25 patients (12%) undergoing endovascular TAA exclusion showed long-segment thoracic aortic coverage to be a significant risk factor in predicting clinically evident spinal cord ischemia [2]. Endoluminal repair allows the avoidance of aortic cross-clamping, however, the intercostal arteries covered by the stent graft cannot be reimplemented. If the intercostal artery for preoperatively detected ARM was present in patients undergoing endovascular procedures for thoracic aortic aneurysm, these patients would have occlusion of the intercostal artery for ARM due to stent-graft. However, we have experienced patients who do not have paraplegia/paraparesis after endovascular stent-graft repair with sacrifice of the preoperatively detected intercostal artery for ARM. The mechanism underlying the occurrence of spinal cord ischemia after thoracic endovascular aortic repair has yet to be completely understood, because paraplegia results not only in severe physical disability but is also associated with decreased survival rates.

In this study, we reviewed our experience to investigate the determinants of paraplegia/paraparesis after endovascular stent-graft repair of the thoracic aorta, to assess the influence of the artery of Adamkiewicz (ARM) detected by preoperative magnetic resonance angiography (MRA) and to identify patients at risk.
2. Materials and methods

2.1. Patients

During a period of about 5 years (March 2001—June 2006), 149 patients underwent elective endovascular stent-graft repair of the descending thoracic aorta. Data from the hospital records of these patients were obtained from our departmental registry. The site of proximal or distal endograft deployment is shown in Fig. 1 according to the aortic map proposed by Ishimaru [3]. The length of stent-graft deployed was represented by zone numbers in the thoracic aorta between proximal landing zone and distal landing zone.

Eighty-three of 149 patients underwent MRA for detection of the ARM. ARM was detected in 71 of these 83 patients. To assess the influence of the ARM in the thoracolumbar region, patients in whom ARM was detected by preoperative MRA were divided into two groups: patients who had occlusion of the intercostal artery for ARM due to stent-graft (group A, n = 33) and patients who had patency of the intercostal artery for ARM following stent-graft (group B, n = 38).

2.2. Stent-graft placement

The stent-grafts were hand-made using Gianturco Z stents (Cook Inc., Bloomington, IN, USA), which were preconstructed to fit the aortic tortuosity, covered with a UBE prosthetic vascular graft (Ube Corp, Ube, Japan). We utilized various types (9 cm, 12 cm, 16 cm and 20 cm lengths using 20 mm, 30 mm and 40 mm wide stents) of endoskeleton consisting of 2.5-cm-long Z-stents that had been gas-sterilized and stored in our hospital so as to be available immediately if required. Z-stents are attached to each other with solder, leaving spaces of 8 mm between stents.

Axial CT images were used to determine the diameter of the landing zone and the length of the endoskeleton. The procedure has been described in detail in a previous report [4]. Briefly, the patient was placed on a radiolucent operating table under general anesthesia in the operating room.

The hand-made stent-graft was manually loaded into a proximal end of an 18F to 22F sheath (Cook Inc.), depending on the dimensions of the stent-graft. The delivery system was advanced to the target region over the guidewire. The sheath was withdrawn after DSA confirmed the exact localization in relation to the head vessels, primary entry tear, and the diseased aortic segment. For patients with dissection, positioning of the guidewire into the true lumen was verified with intravascular ultrasonography. When a postprocedural DSA demonstrated endoleak, balloon dilatation was performed.

2.3. MR angiography

2.3.1. Imaging protocol and data processing

MRA was performed with a 1.5-T unit (SIGNA Horizon LX Echospeed and with a SIGNA Infinity Excite (from January 2003) (GE Medical Systems, Milwaukee, WI)). Since reconstruction of the radicular artery is considered necessary for aortic graft replacement in our institute, a 20-cm field of view (FOV) from above the L2 level was examined in each patient. Dynamic study was carried out by the enhanced three-dimensional fast spoiled GRASS (FSPGR) method (phased array spine coil; TR/TE/flip angle, minimum/minimum/10-5 degrees; NEX, 2; matrix, 256×128; slice thickness, 1.6 mm; zero fill interpolation (slice ZIP 4 and in-plane ZIP 512); no phase wrap; FOV, 20 cm; oblique-coronal section along the posterior line of the vertebral body). Gadolinium-diethylenetriaminopentaacetic acid (Gd-DTPA; MAGNEVIST, Schering, Berlin, Germany) was injected via the cubital vein (0.2 mmol/kg, 4 ml/s) followed by a 20-ml saline flush. A power injector (OPTISTAR MR; Mallinckrodt, St. Louis, MO) was used in all patients. After injection, dynamic studies were carried out five times. Scan times were 22 s for each session. After data acquisition, the images were stored as DICOM data sets and displayed on a diagnostic monitor at a 0.4-mm reconstruction pitch.

The acquired data sets were transmitted to a workstation (Advantage Windows, GE Medical Systems, Milwaukee, WI). The maximum intensity projection (MIP) image was recon-
structed in each of five phases. The resulting five MIP images were used for subtraction. The second to fifth phase images were subtracted. The first phase image was subtracted from the resulting four subtraction images (total of five MIP) were presented in a movie format that followed the imaging time course.

2.3.2. Criteria for detection of the artery of Adamkiewicz

Criteria for detection of the ARM on source and MIP images was as follows: (1) being continuous to a clear blood vessel supply from the intercostal or lumbar artery in an early phase image, (2) identification of extension of a blood vessel from the dorsal branch of the intercostal or lumbar artery toward the surface of the anterior spinal cord in the early phase and (3) diminishing vascular signal intensity in late phase [5].

2.4. Statistical analysis

Data were processed using Stat View J-5.0 software (Abacus Concepts Inc., Berkeley, CA). Variables in groups A and B were compared using the \( \chi^2 \) test, Fisher’s exact test, Student’s t-test and Mann–Whitney U-test. Data for times and age are presented as means \( \pm SD \).

3. Results

Data on the branching levels of the ARMs are presented in Fig. 2. ARMs were detecting in 71 (84.5%) of 84 patients in whom detection by preoperative MRA was attempted, from a total of 149 patients that underwent elective endovascular stent-graft repair. All 71 patients had vessels that coursed toward the anterior spinal cord and were supplied from the intercostal artery. Only one ARM was detected in 59 (83.1%) of the 71 patients, whereas two ARMs were detected in each of the other 12 (16.9%) patients. The laterality of the arteries originated from the intercostal artery on the left side in 78 (94.0%) of the 83 ARMs. In the 12 patients in whom two ARMs were detected, the ARMs originated unilaterally in 10 patients and bilaterally in 2 patients, and the ARMs were between Th9 and Th11 in 69 (83.1%) of the 83 ARMs.

To assess the influence of the ARM in the thoracolumbar region, patients in whom ARM was detected by preoperative MRA were divided into two groups: patients who had occlusion of the intercostal artery for ARM due to stent-graft (group A, \( n = 33 \)) and patients who had patency of the intercostal artery for ARM following stent-graft (group B, \( n = 38 \)). In 3 (9.1%) of the 33 patients in group A, spinal cord ischemia developed after endovascular stent-graft repair. No patient in group B had symptoms of spinal cord ischemia (Table 1). Group A had a trend of an increased risk of neurologic deficit (paraparesis/paraplegia) (\( p = 0.09 \)). The length of stent-graft deployed was 7.5 \( \pm 2.0 \) zone numbers in group A, and 6.0 \( \pm 1.1 \) zone numbers in group B. The length of stent-graft deployed in group A was significantly longer than in group B (\( p = 0.0003 \)). In group B, occlusion of intercostals artery to the Adamkiewicz artery was avoided and therefore stent-graft insertion range was short, and there was a significant difference in frequency of proximal or distal landing zone of patients between the two groups (Table 2).

One of the three patients had the stent-graft at a site distal to a previous graft replacement of descending thoracic aorta. Paraparesis occurred in two of three cases of spinal cord ischemia and paraplegia in one case. This patient suddenly had back pain and developed acute bilateral lower extremity weakness on postoperative day 32. Neurologic examination demonstrated weakness of both psoas muscles and loss of sensation to Th10 level consistent with delayed spinal cord ischemia (Table 3).

From all the 71 elective endovascular stent-graft repair patients in whom detection ARM was detected by preoperative MRA, 3 (4.2%) manifested postoperative neurologic deficits due to spinal cord ischemia. The length of stent-graft

![Fig. 2. Frequency of vertebral level termination and laterality of Adamkiewicz arteries in groups A and B.](image-url)
deployed was $8.7 \pm 0.6$ zone numbers in the neurologic deficits (paraparesis/paraplegia) group, and $6.6 \pm 1.8$ zone numbers in the no neurologic deficits group. The length of stent-graft deployed in the neurologic deficits group was significantly longer than in the no neurologic deficits group ($p = 0.04$) (Table 4).

### 4. Discussion

Existing experience with endovascular stent-graft repair of isolated descending thoracic aortic aneurysms indicates that spinal cord ischemia remains a serious complication, with a reported frequency that ranges from 0% to 12.0% [2,6—17] (Table 5).

Glade et al. performed a small meta-analysis of a cumulative cohort of patients reported in recent literature, who were treated for a descending aneurysm by endovascular stent-graft repair or open repair [18]. From their meta-analysis of pooled data on more than 1000 patients it can be concluded that the paraplegia/paraparesis and mortality rate is less for patients treated by endovascular stent-graft repair. Finally, candidates for endovascular stent-graft repair were often older patients with more comorbidities, who may not normally be considered candidates for open repair. Even in studies on patients who received stent-grafts because they were unfit to undergo open repair the pooled mortality and paraplegia/paraparesis rate is reported to be significantly lower in patients treated with an endovascular stent-graft.

Endovascular repair avoids aortic cross-clamping and may significantly decrease perioperative complications because of the minimally invasive nature of the procedure and avoidance of ischemia/reperfusion and the associated changes in hemodynamics that occur during proximal aortic cross-clamping. However, it does not eliminate the risk of spinal cord ischemia. Explanations for the persistent risk of spinal cord ischemia after endovascular stent-graft repair include coverage of a greater extent of aorta to achieve an ideal seal for the graft further away from the aneurysm [19]. In contrast to open repair, intercostal arteries that could potentially be reattached must be sacrificed after endovascular stent-graft repair.

Published series have also reported that prior abdominal aortic aneurysm repair and the length of the stent-graft were risk factors for spinal cord ischemia [2,6—9,16]. The greater risk of spinal cord ischemia in patients with prior abdominal aortic aneurysm repair may be explained by possible compromise of pelvic and hypogastric collateral that supply the anterior spinal artery [20,21].

Many patients in group A in whom Adamkiewicz artery was detected by MRA did not have spinal cord ischemia after endovascular stent-graft repair even if the intercostal artery to ARM was occluded by inserting the stent-graft. There has been a great difference of opinion regarding the importance of reimplanting the intercostal artery to ARM in open repair. All 33 patients of group A had occlusion of the intercostal artery to ARM and we were surprised that spinal cord ischemia occurred in only 3 of these 33 patients (Table 1). The frequency of spinal cord ischemia increases if the intercostal artery to ARM is occluded. However, we believe there are many cases that are not always dependent on the blood supply from ARM, as evidenced by the fact that there were patients who did not have spinal cord ischemia after

### Table 2

<table>
<thead>
<tr>
<th>Zone</th>
<th>Proximal*</th>
<th>Distal**</th>
<th>Proximal*</th>
<th>Distal**</th>
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<tr>
<td>Z0</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td>Z2</td>
<td>7</td>
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<td>Z4</td>
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<td>3</td>
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<td>Z5</td>
<td>6</td>
<td>11</td>
<td>14</td>
<td>3</td>
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<td>Z6</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
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<td>Z7</td>
<td>3</td>
<td>1</td>
<td>3</td>
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<td>Z8</td>
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<td>Z9</td>
<td>9</td>
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<td>Z10</td>
<td>13</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>L1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>L2</td>
<td>2</td>
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<td>1</td>
</tr>
<tr>
<td>L3</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Mann–Whitney’s U-test.

* $p < 0.0001$.

** $p < 0.0001$.

### Table 3

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Age</th>
<th>Sex</th>
<th>Proximal landing zone</th>
<th>Distal landing zone</th>
<th>Zone number</th>
<th>ARM</th>
<th>Spinal cord injury</th>
<th>Prior aortic surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I.C.</td>
<td>63</td>
<td>M</td>
<td>T5</td>
<td>T12</td>
<td>8</td>
<td>Left T12</td>
<td>Paraparesis</td>
<td>Descending</td>
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<tr>
<td>2</td>
<td>M.M.</td>
<td>72</td>
<td>M</td>
<td>Z3</td>
<td>T11</td>
<td>9</td>
<td>Left T9</td>
<td>Paraparesis</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>T.K.</td>
<td>78</td>
<td>M</td>
<td>T4</td>
<td>T12</td>
<td>9</td>
<td>Left T10</td>
<td>Paraplegia</td>
<td>No</td>
</tr>
</tbody>
</table>

### Table 4

<table>
<thead>
<tr>
<th>Patients</th>
<th>Total elective patients (n = 71)</th>
<th>$p$ value*</th>
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</thead>
<tbody>
<tr>
<td>No paraplegia (n = 68)</td>
<td>Paraparesis/paraplegia (n = 3)</td>
<td></td>
</tr>
<tr>
<td>Male/female</td>
<td>54 (79)/14 (21)</td>
<td>3 (100)/0 (0)</td>
</tr>
<tr>
<td>Age (mean ± SD)</td>
<td>69 ± 13</td>
<td>71 ± 7.6</td>
</tr>
<tr>
<td>Dissection</td>
<td>17 (25)</td>
<td>1 (33)</td>
</tr>
<tr>
<td>Nondissection</td>
<td>51 (75)</td>
<td>2 (67)</td>
</tr>
<tr>
<td>Zone number (mean ± SD)</td>
<td>6.6 ± 1.8</td>
<td>8.7 ± 0.6</td>
</tr>
<tr>
<td>Type I endoleak</td>
<td>6 (8.9)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Type II endoleak</td>
<td>1 (1.5)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Type III endoleak</td>
<td>1 (1.5)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Prior aortic surgery</td>
<td>32 (47)</td>
<td>1 (33)</td>
</tr>
<tr>
<td>Hospital mortality</td>
<td>3 (4.4)</td>
<td>0 (0)</td>
</tr>
</tbody>
</table>

Zone number; zone number from proximal zone to distal zone.

* Fisher’s exact test.

** Unpaired Student’s t-test.

#c Mann–Whitney U-test.
occlusion of the intercostal artery to ARM in endovascular stent-graft repair. In group B, occlusion of intercostal artery to ARM was avoided, and therefore the stent-graft insertion range was short; thus, there was a significant difference between the two groups (Table 3).

Of all the 71 elective endovascular stent-graft repair patients in whom detection ARM was detected by preoperative MRA, 3 (4.2%) exhibited postoperative neurologic deficits as a result of spinal cord ischemia. These three patients had occlusion of the intercostal artery for ARM after endovascular stent-graft repair and one of these three patients had undergone previous operation for descending thoracic aorta graft replacement. For patients who had spinal cord ischemia after endovascular stent-graft repair, a stent-graft which covered the greater extent of the aorta was implanted (Table 4). One difference with open repair is the cross-clamping of the aorta, which causes spinal cord perfusion pressure decrease by steel phenomenon of bleeding from intercostal arteries. If total blood flow quantity in the spinal cord becomes equal to or less than a certain constant level, patients will suffer spinal cord ischemia.

In some cases ARM is very important to maintain total blood flow quantity, but some patients do not have spinal cord ischemia even if the intercostal artery to ARM is occluded after stent-graft procedure. In this study, it appeared that ARM did not bear much responsibility for total blood flow quantity to the spinal cord. However, patients who do not have spinal cord ischemia even if intercostal artery for ARM is occluded after endovascular stent-graft repair may nonetheless have paraplegia or paraparesis after open surgery. The ‘Map’ of blood flow in the spinal cord is different between individuals and the ‘Map’ will change after surgery for abdominal aortic aneurysm or thoracic aortic aneurysm.

The ‘dam’ theory maintains that no single artery is so important, but rather it is the total amount of blood flow through all intercostal and lumbar arteries or vertebral arteries from the subclavian artery or pelvic vascular plexus that determines adequacy of spinal cord perfusion. To use an analogy, if the ARM, was a big river flowing into a dam, even if this river’s water failed to reach the dam, dam would still be supplied by water if there were many other rivers. If, on the other hand, there were few rivers except for the ARM, the dam would soon run dry. Moreover, bleeding from intercostal arteries during open surgery can also contribute to a reduction in the blood supply to the spinal cord. In these cases, reconstruction of the intercostal artery for ARM is probably necessary in order to maintain sufficient blood flow to the spinal cord during open surgery.

In conclusion, the use of stent-grafts in the management of aortic aneurysms has the theoretic advantage of lowering the incidence of paraplegia/paraparesis because there is no period of aortic cross-clamping, but the length of the stent-graft was found to be a significant predictor of spinal cord ischemia, and therefore when the inserted stent-graft is long, vigilance is needed regarding occlusion of the intercostal artery for ARM detected prior to endovascular stent-graft repair.

### Table 5

<table>
<thead>
<tr>
<th>First author</th>
<th>Year</th>
<th>Patients endo (n)</th>
<th>Postoperative SCI</th>
<th>Risk factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moon [7]</td>
<td>1997</td>
<td>18</td>
<td>1 (5.6%)</td>
<td>AAA repair</td>
</tr>
<tr>
<td>Semba [8]</td>
<td>1997</td>
<td>44</td>
<td>2 (5%)</td>
<td>AAA repair</td>
</tr>
<tr>
<td>Gravereaux [9]</td>
<td>2001</td>
<td>53</td>
<td>3 (5.7%)</td>
<td>AAA repair, short graft</td>
</tr>
<tr>
<td>Criado [10]</td>
<td>2002</td>
<td>74</td>
<td>0 (0%)</td>
<td>Not described</td>
</tr>
<tr>
<td>Ellays [11]</td>
<td>2003</td>
<td>84</td>
<td>3 (3.6%)</td>
<td>Not described</td>
</tr>
<tr>
<td>Bell [12]</td>
<td>2003</td>
<td>67</td>
<td>3 (4%)</td>
<td>Not described</td>
</tr>
<tr>
<td>Bergeron [13]</td>
<td>2003</td>
<td>38</td>
<td>0 (0%)</td>
<td>Not described</td>
</tr>
<tr>
<td>Orend [14]</td>
<td>2003</td>
<td>74</td>
<td>2 (3%)</td>
<td>Not described</td>
</tr>
<tr>
<td>Czerny [15]</td>
<td>2004</td>
<td>54</td>
<td>0 (0%)</td>
<td>Not described</td>
</tr>
<tr>
<td>Cheung [16]</td>
<td>2005</td>
<td>75</td>
<td>5 (6.3%)</td>
<td>AAA repair, hypotension</td>
</tr>
<tr>
<td>Chiesa [17]</td>
<td>2005</td>
<td>99</td>
<td>4 (4.0%)</td>
<td>Perioperative hypotension</td>
</tr>
</tbody>
</table>

### References


Appendix A. Conference discussion

Dr M. Grabenwoger (Vienna, Austria): The aortic arch replacement, was this done in the same setting? Is this a one-stage repair, arch and descending aorta, or was this, first, aortic arch replacement and several weeks later stenting the descending aorta?

Dr Kawaharada: At first it was total arch replacement with elephant trunk. After that we had stent-grafting in the descending aorta with two stage repair.

Dr Grabenwoger: After?

Dr Kawaharada: Yes.

Dr M. Turina (Zurich, Switzerland): Maybe a comment that your results very closely parallel the previously obtained results with open surgery, that any previous surgery in the infrarenal aorta or in the ascending aortic arch is a risk factor for paraplegia. This has been already well established in the open literature. So it is not surprising that you are finding the same thing, because previous surgery might have eliminated some of the collaterals.

Dr Kawaharada: I don’t know the details, but I think that prior graft replacement is very important for spinal injury after stent-grafting. I don’t now have data of occlusion of the intercostal artery in open surgery.

So I cannot intentionally occlude the important intercostal artery in open surgery. But I think that open surgery is different from endovascular stent-grafting. You say that my paper is not good.

But I can’t find any paper about study of stent-grafting repair after detecting the Adamkiewicz artery.

Dr B. Ziepfel (Berlin, Germany): Your idea of the river and the dam and the back flow is quite good, but in endografting you may have back flow as well if you have a Type II endoleak, if you have back flow from the intercostal arteries that you see in the abdominal aorta quite often, but we don’t see it very often in the thoracic aorta. Maybe this is a reason, or maybe this is a finding which is combined. So we should look whether we can relate it to the rare Type II endoleaks. If you have a real Type II endoleak with an outflow, then you may have this kind of steal phenomenon.

Dr Kawaharada: About the endoleak, I had a few patients after endovascular surgery evaluated with a CT scan. That CT scan resulted that the intercostals arteries were all occluded but Adamkiewicz artery was patent. If there is type II endoleak after stent-grafting, the intercostals artery is not occluded, so the Adamkiewicz artery is patent. Only open surgery is very important in the steal phenomenon by back blood low.

Dr Grabenwoger: Do you recommend now to identify the Adamkiewicz artery in every individual patient according to your results? Should we do this prior to stent-grafting?

Dr Kawaharada: On almost all thoracic aorta patients we try the operation. But you know, in Japan, the Japanese government doesn’t permit to use commercialize stent-grafts. We use a handmade stent-graft. That stent is steel. After the endovascular operation, the patient cannot have evaluation by MRI.