Anatomical mismatch of the pulmonary autograft in the aortic root may be the cause of early aortic insufficiency after the Ross procedure

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Abstract

Objective: Early aortic insufficiency can be a problem after the Ross procedure. Anatomical mismatch and an inexact surgical technique may lead to distortion of the normal pulmonary valve geometry and subsequent incorrect leaflet coaptation and valve insufficiency. In this study, we assessed the efficacy of changing and improving the surgical technique to minimize the early pulmonary autograft valve failure. The modifications and the strategy are discussed. Methods: From January 1995 to February 1999, a total of 77 adults underwent the Ross procedure for aortic valve replacement at Sahlgrenska University Hospital. The operative technique used was full free-standing aortic root replacement with a pulmonary autograft in all cases. In the first 24 cases, the diameter of the pulmonary roots was seldom measured, eye-ballling was used to exclude anatomical mismatch due to a dilated aortic root, and only one attempt of correction was made, which failed. In the other 53 cases, the technique was improved by: (1) reducing the aortic anulus diameter in cases with moderate dilatation; (2) excluding cases with severe dilatation of the aortic annulus; (3) adjusting the diameter of the sinotubular junction of the aorta to the diameter of the sinotubular junction of the pulmonary artery; (4) reimplanting the left ostium in the autograft, and (5) changing the proximal anastomosis technique. Results: In this study, we had an early aortic incompetence of grade 2 in eight patients among the first 24 patients. In the other 53 patients, postoperative echocardiography at 1 week revealed aortic insufficiency of grade 2 in two patients. Conclusions: Aortic insufficiency after the Ross procedure can be minimized by patient selection, intraoperative correction of anatomical mismatch and improved surgical technique. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Aortic valve; Pulmonary autograft replacement; Ross procedure; Aortoplasty; Anuloplasty; Autograft insufficiency

1. Introduction

Pulmonary autograft replacement of the aortic valve was introduced by Sir Donald Ross in 1967 [1]. After the reports of excellent long-term results after the Ross procedure, we have extended the indication for total aortic root replacement with an autograft to adults [2]. The clear advantages for adults include absence of anticoagulation therapy, thromboembolism and audible valve closure (click sound). Other advantages are a low transvalvular gradient, high resistance to endocarditis and superior long-term durability among biological valve replacements in the aortic position [3].

There are drawbacks, however, one being the complexity of the surgical procedure, which is demanding on the surgeon’s skills and often leads to a learning curve affecting the results.

At Sahlgrenska University Hospital, we have used the Ross procedure in adults for aortic valve replacement. In the first 24 patients, postoperative echocardiography at 1 week revealed aortic insufficiency grade 2 in eight patients. Although this did not necessitate surgical intervention, it is still of concern because of the risk of progressive dilatation with time, and it is an unacceptable result with a procedure for which a safer alternative exists.

In this study, we assessed the efficacy of improving surgical technique and adjusting anatomical mismatch by changing the strategy for minimizing the early autograft valve failure. The modifications and the strategy are discussed.

2. Materials and methods

2.1. Patients

A total of 77 patients underwent the Ross procedure at
Thirty-six patients presented with aortic stenosis, 23 with incompetence and 18 with combined defects. In 28 patients, there was a bicuspid aortic valve (six in the first 24 cases and 22 in the other 53 patients), in one patient a tricuspid valve, in one patient unknown, and in 42 patients a tricuspid valve. Five patients had previous aortic valve replacement. Three patients had undergone aortic prosthesis replacement due to pericarditis dysfunction. One patient had a replacement of a homograft due to a ruptured cusp. Three patients had endocarditis; of these one had an aortic mechanical valve with endocarditis and paravalvular leakage, one a previous commissurotomy, and one had to undergo immediate surgery because his condition was acute. Previous commissurotomy had been performed in nine cases. Patient characteristics are shown in Table 1.

### 2.2. Bypass and cardioplegia

Standard cardiopulmonary bypass techniques under moderate hypothermia (32°C rectal temperatures) were used. Cold (4°C) intermittent antegrade crystalloid cardioplegia delivered in the coronaries was used for myocardial protection in the first 24 cases. For the remaining 53 patients, this was changed to cold (4°C) intermittent retrograde blood cardioplegia and cold (4°C) intermittent antegrade blood cardioplegia delivered in the right coronary ostium (because of the risk of malprotection of the right ventricle during retrograde perfusion). The mean aortic crossclamp time and the perfusion time are given in Table 2.

### 2.3. Surgical technique

The surgical technique used was full free-standing aortic root replacement with a pulmonary autograft in all cases.

<table>
<thead>
<tr>
<th>Sex</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>52</td>
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<tr>
<td>Female</td>
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<table>
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<th>NYHA Class</th>
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<tr>
<td>Class III</td>
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<tr>
<td>Class IV</td>
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<table>
<thead>
<tr>
<th>EF (%)</th>
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<tbody>
<tr>
<td>&lt;40%</td>
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<td>40–60%</td>
<td>32</td>
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<tr>
<td>&gt;60%</td>
<td>43</td>
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<table>
<thead>
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<th>n</th>
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<th>n</th>
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<tr>
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</tbody>
</table>

### Table 1

Patient characteristics (n = 77)

### Table 2

Operative characteristics (n = 77)

<p>| | |</p>
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Bypass time (min; mean ± SD)</td>
<td>217 ± 60</td>
</tr>
<tr>
<td>Crossclamp time (min; mean ± SD)</td>
<td>173 ± 38</td>
</tr>
</tbody>
</table>

The aortic root was completely resected and the right coronary ostium was excised from the aortic wall with a cuff and reimplanted in the pulmonary autograft in all cases. The autograft was harvested with special care to avoid injury to the first septal branch of the anterior descending coronary artery. A flush of cardioplegia was given in the left coronary artery to identify arteries, and retrograde in the coronary sinus to identify veins in the dissection area of the posterior wall of the right ventricular outflow tract. These vessels were coagulated or sutured. The outflow tract was reconstructed with a fresh or cryopreserved homograft from cardiac transplant recipients, mainly from our own homograft bank. The homograft was the same size as the patient’s own pulmonary valve or slightly larger. Additional surgical procedures performed are shown in Table 3.

### 2.4. Early experience

In the first 24 cases, the left ostium was retained with a tongue of the aortic wall. The proximal autograft anastomosis was performed with the autograft inverted into the left ventricular outflow tract and with a continuous 4.0 polypropylene (Prolene®) suture line. In the first 24 cases, the diameter of the pulmonary roots was seldom measured. Eye-ball was used to exclude anatomical mismatch due to dilated aortic root, and only one attempt of correction was made, which failed.

### 2.5. Measurements

The diameter of the pulmonary root is best measured by intraoperative transeosophagal echocardiography (TEE) at the sinotubular junction (the ridge immediately above the commissures). The pulmonary valve is calculated to be 10–15% larger, as described by David [4]. The diameter of the aortic root was measured by TTE at the level of the anulus and the sinotubular junction. Intraoperatively, when the aortic valve was excised, the measurement of the aortic anulus was confirmed with valve sizers.

### Table 3

Additional surgical procedures

<table>
<thead>
<tr>
<th>Procedure</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closure of ventricular septal defect</td>
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</tr>
<tr>
<td>Closure of atrial septal defect</td>
<td>2</td>
</tr>
<tr>
<td>Mitral valve replacement</td>
<td>1</td>
</tr>
<tr>
<td>RCA grafting</td>
<td>5</td>
</tr>
<tr>
<td>LAD grafting</td>
<td>2</td>
</tr>
<tr>
<td>AV-fistula</td>
<td>1</td>
</tr>
<tr>
<td>Resection of subaortic membrane</td>
<td>2</td>
</tr>
<tr>
<td>Replacement of ascending aorta</td>
<td>1</td>
</tr>
</tbody>
</table>
2.6. Modifications

In the latest 53 cases, the technique was improved by the following methods:

1. Reducing the aortic anulus diameter in cases with moderate dilatation.
   If the calculated diameter of the pulmonary anulus was similar to or larger than the aortic anulus measured with valve sizers, the pulmonary root was implanted without correction of the aortic anulus. If the diameter of the aortic anulus was larger than the diameter of the pulmonary anulus, reduction of the anulus was performed. The diameter was reduced by reducing the circumference according to the following formula: circumference = diameter × 3.14. For example, a difference in one valve size, that is 2 mm, necessitates a circumference reduction of 6.5 mm. A strip of Teflon (PTFE-felt, Meadox) about 5 mm wide was used to reduce the circumference in the area between the two fibrous trigones where dilatation occurs. The Teflon strip was placed outside the aortic root in a subanular position at the same level as the autograft implant. The strip of Teflon was attached with a mattress suture at each end and the circumference of the anulus was reduced as required. The Teflon strip was then attached to the outflow tract by plicating the subanular region against the Teflon strip using the mattress sutures as continuous sutures from each side and meeting in the middle (Fig. 1.). After the anuloplasty was completed, the anulus was measured with valve sizers and the diameter checked. This Teflon strip can also be used to prevent later dilatation. The number of anuloplasties performed is shown in Table 4, and the anulus diameter before and after anuloplasty compared to the calculated autograft diameter is presented in Table 5.

2. Excluding cases with severe dilatation of the aortic anulus.
   If the aortic anulus measured with valve sizers differed by more than two valve sizes compared to the calculated diameter of the pulmonary anulus, the procedure was not performed. We feel that a reduction of more than 12–13 mm is inadvisable for safety reasons.

3. Adjusting the diameter of the sinotubular junction of the aorta to the diameter of the sinotubular junction of the pulmonary artery.
   If the diameter of the aorta at the level of the sinotubular junction corresponded to the diameter of the pulmonary sinotubular junction, the distal anastomosis was performed. If the diameter of the aorta was larger than the diameter of the pulmonary sinotubular junction, the aorta was reduced. The reduction was performed with an aortoplasty in which the aortic wall was duplicated and sutured and reinforced with a Teflon strip at each side. After the aortoplasty was completed, the aorta was measured with valve sizers and the diameter confirmed (Fig. 2.). If there was not only a mismatch but also an aneurysm of the aorta, the ascending aorta was removed and a homograft of a size corresponding to the sinotubular junction of the autograft was used as an interponate. The number of aortoplasties performed is shown in Table 4.

4. Reimplanting the left ostium in the autograft.
   The technique was changed and the left ostium was excised from the aortic wall and reimplanted in the autograft (Fig. 3). The distal anastomosis technique was changed from one continuous suture line to three continuous 4:0 polypropylene (Prolene<sup>®</sup>) suture lines. Care was taken to divide the circumference of the autograft and the circumference of the ascending aorta into three equal parts, anastomosing each part of the autograft to a corre-

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**Table 4**

<table>
<thead>
<tr>
<th>Correction of size mismatch</th>
</tr>
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<tbody>
<tr>
<td>Aortic anulus reduction</td>
</tr>
<tr>
<td>Reduction of the ST-junction of the aorta</td>
</tr>
<tr>
<td>Replacement of ascending aorta</td>
</tr>
</tbody>
</table>

**Table 5**

Aortic anulus diameter before and after anuloplasty (calculated pulmonary anulus diameter is presented as autograft diameter)*

<table>
<thead>
<tr>
<th>Patient no</th>
<th>Aortic anulus diameter (mm)</th>
<th>Autograft diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before anuloplasty</td>
<td>After anuloplasty</td>
</tr>
<tr>
<td>40</td>
<td>26</td>
<td>24</td>
</tr>
<tr>
<td>43</td>
<td>33</td>
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<td>44</td>
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<td>73</td>
<td>29</td>
<td>27</td>
</tr>
<tr>
<td>76</td>
<td>27</td>
<td>25</td>
</tr>
</tbody>
</table>

Mean ± SD 29.0 ± 2.5 25.9 ± 2.2

*P value <0.005 (before vs. after anuloplasty).

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Fig. 1. Anuloplasty.
sponding part of the aorta with one continuous suture line. In this way, the risk of mismatch and malpositioning was minimized.

5. Changing the proximal anastomosis technique.

To simplify spacing, the autograft was not inverted and the proximal anastomosis was performed with interrupted sutures (30-40) placed in a subanular horizontal line corresponding to the horizontal proximal end of the autograft (Fig. 3). The mid-cusp points in the aortic anulus were defined with a Toronto valve sizer, which is marked at each 120°, dividing the circumference into three equal parts. These points were marked with three sutures to serve as guides. The corresponding points in the autograft were also marked. The suture material used was 4:0 silicon-treated braided polyester (Ti-Cron, Davis and Geck). We use blue and white sutures alternately to simplify identification of corresponding suture ends.

2.7. Postoperative echocardiography at 1 week

Echocardiography was performed using an Acuson Computed Sonograph (Acuson, Mountain View, CA, USA). The ejection fraction was calculated either from M-mode or from two-dimensional recordings. All the patients were investigated by color Doppler, as well as by pulsed and continuous wave Doppler. When image quality did not allow calculation, the ejection fraction was assessed by eyeballing.

The assessment of aortic insufficiency severity was based on a number of variables: color Doppler jet characteristics including jet width and area, continuous wave Doppler intensity and shape of the spectral recording, left ventricular dimensions and pulmonary artery pressure [5,6]. These variables are either directly influenced by aortic insufficiency severity or related to compensatory changes in the heart. All patients were graded on a four-point scale. Grades 3 and 4 indicate severe insufficiency.

2.8. Statistical analysis

Categorical data are given as total numbers; continuous variables are given as mean ± SD. Differences between groups were assessed by the two-tailed Student’s t-test for independent variables, and significance assumed for P-values less than 0.05.

3. Results

The early mortality (30 days) for the whole group was three patients (4%). One patient with a previous commissurotomy presenting with a combined defect and a left ventricular ejection fraction of 30% had an extensive myocardial infarction. He received a left ventricular assist device (LVAD), but did not recover and died of multiorgan failure on day 7. The second patient had an uneventful operation and died after discharge; the autopsy showed no abnormality. The third patient had a postoperative episode of hypertension during transport to the ICU and subsequent massive bleeding necessitating reexploration. A proximal autograft suture line rupture was successfully repaired but resulted in right ventricular failure. This patient was treated with an intra-aortic balloon pump (IABP) and right ventricular assist device (RVAD) but the myocardial function was not...
restored. On day 17, he received a transplant but unfortunately developed biventricular donor heart failure and died.

In the first 24 cases, early postoperative complication was bleeding, necessitating reoperation in four patients (16%): in one patient from the distal anastomosis of the autograft, in one from the back wall of the vena cava superior, and in two due to tamponade where no obvious source of bleeding was found. In the other 53 patients, reoperation for bleeding was required in four patients (7.5%): in one patient from the right outflow tract, in one patient from a partial rupture of the proximal suture line due to postoperative hypertension, which was successfully repaired, and in two patients in whom no obvious source of bleeding was found.

Other early postoperative complications included transient cerebral ischemic attacks due to postoperative fibrillation in one patient and pacemaker insertion in one patient. Four patients had perioperative myocardial infarction. Two patients had a fatal myocardial infarction and are included in the early mortality figure. Two patients had a non-fatal myocardial infarction. A 40-year-old woman had postoperative electrocardiographic evidence of myocardial ischemia suspected with TTE and confirmed with postoperative coronary angiography, which showed a proximal LAD stenosis (this patient had not had a preoperative coronary angiography). The patient was reoperated on and underwent a bypass with a left internal mammary artery to the LAD. This patient did well. The other patient was weaned from cardiopulmonary bypass and developed right ventricular failure. When disturbance of the right coronary artery was suspected, a coronary bypass with a saphenous vein graft to the right coronary artery was performed. This patient also did well.

Two patients with no autograft insufficiency after the procedure required additional sutures to achieve hemostasis: in one patient in the proximal autograft anastomosis and in the other in the left coronary anastomosis. Unfortunately, these extra sutures caused aortic insufficiency, in the first patient probably by causing anatomical mismatch and in the latter by grasping the left coronary cusp. An option, at this point, was replacement with an aortic valve homograft, but the surgeon was uncertain of the additional time for thawing a frozen homograft and whether prolonging the aortic cross clamping time might influence the outcome. These patients were converted to mechanical composite grafts and did well.

In the first 24 patients, postoperative echocardiography at 1 week revealed grade 2 insufficiency in eight patients (33%). Five were tricuspid and four out of these were dilated (28, 30, 31 and 38 mm) and one was normal (27 mm); Three were bicuspid and one of these was dilated (32 mm) and two were normal (20 and 24 mm). In the other 53 consecutive patients, postoperative echocardiography at 1 week revealed grade 2 insufficiency in two patients (4%). One of these was bicuspid and the other tricuspid. Both these valves had normal dimensions (24 and 22 mm). The echocardiographic results are shown in Table 6.

<table>
<thead>
<tr>
<th>Score</th>
<th>Early (24 pts)</th>
<th>Late (53 pts)</th>
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<tbody>
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<td>Grade 0</td>
<td>7</td>
<td>38</td>
</tr>
<tr>
<td>Grade 1</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>Grade 2</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Grade 3–4</td>
<td>0</td>
<td>0</td>
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</table>

In 25 patients, the diameter of the aortic anulus and/or the ascending aorta was reduced. Out of these, echocardiography at 1 week revealed no insufficiency in 18 patients (in one with anuloplasty only, in nine with aortoplasty only, in seven with anuloplasty and aortoplasty, and in one with anuloplasty and homograft), grade 1 insufficiency in six patients (five with aortoplasty only and one with anuloplasty and aortoplasty) and grade 2 insufficiency in one patient (aortoplasty only).

4. Discussion

The most common technique used for aortic valve replacement with the pulmonary autograft is free-standing root replacement [7–9]. The free-standing root technique preserves the anatomical unit of the pulmonary root and may reduce the potential risk of incorrect anatomical positioning. In spite of this, early aortic incompetence and reoperation after the Ross procedure have been reported by several groups [8,10]. In this study, we had an unacceptable early incompetence in the first 24 patients.

The key to achieving sufficiency of the autograft is an understanding of its anatomical relations. We felt that anatomical mismatch and an incorrect surgical technique may lead to distortion of the normal pulmonary valve geometry and subsequent incorrect leaflet coaptation and valve insufficiency. This problem can occur both at the level of the proximal and the distal anastomosis.

If the autograft anulus dilates due to size mismatch, the leaflet attachments are pulled laterally, causing central leakage. If the pulmonary sinotubular junction dilates due to size mismatch between a smaller pulmonary sinotubular junction and a larger aortic sinotubular junction, the commissures in the autograft are pulled out, leading to defective coaptation and central leakage. An incorrect proximal and/or distal anastomosis technique may also lead to distortion of the pulmonary valve geometry and lead to incorrect leaflet coaptation and subsequent leakage.

In the first 24 patients, a preoperative TTE was performed in all cases. Of the eight patients that developed early grade 2 aortic insufficiency, only three were evaluated as having a normal aortic anulus diameter (20, 24 and 27 mm), and five were dilated (28, 30, 31, 32 and 38 mm). This experience indicated that anatomical mismatch of the pulmonary and aortic anulus may contribute to aortic valve insufficiency.

Even with a normal aortic anulus diameter and a compe-
tent pulmonary valve on preoperative TTE, early aortic insufficiency developed. This was interpreted as being due
to a technical error during implantation of the autograft.

In this study, we have modified the strategy according to
two main principles; one is correction of anatomical mismatch and the other is optimizing the surgical technique,
to achieve less aortic insufficiency.

Correction for autograft to aortic anulus and aortic sino-
tubular junction mismatch requires reproducible and reli-
able measurements. Because of the difficulty in measuring
the pulmonary valve anulus correctly by transthoracic or
transoesophageal echocardiography, due to technical errors,
these measurements were not used in this study. We have
chosen to measure the pulmonary sinotubular junction by
intraoperative TEE and to calculate the pulmonary valve
anulus [4]. Assessing the sinotubular junction and/or
the anulus of the pulmonary root with valve sizers was not
used in this study, due to the risk of overdistension.

The reason for excluding cases with severe dilatation
of the aortic anulus is that it is more difficult to perform a
reduction in these cases, with a higher risk of technical
errors. Furthermore, there is a risk that these cases with
severe dilatation have a disorder involving the connective
tissue, which could lead to progressive dilatation.

The Teflon strip was used not only to reduce the diameter
but also to prevent later dilatation. One could argue that this
precaution could be taken in cases with severe dilatation
after a reduction, but with the experience of having an unac-
tetable rate of grade 2 early incompetence we adopted a
cautious attitude.

To perform the proximal anastomosis with interrupted
sutures is more time-consuming, but in our experience
worthwhile because it simplifies spacing and reduces
the risk of distorting of the normal pulmonary valve geometry.
At first, polypropylene sutures were used. Due to the stiff-
ness of this material, it was difficult to keep all sutures in
order after the sutures were placed and before they were tied
one-by-one. We therefore changed to 4:0 silicon-treated
braided polyester. This suture material is smooth and easy
to handle.

Retention of the left ostium with a tongue of the aortic
wall reduces the risk of kinking of the left coronary artery
and eliminates the need for one coronary anastomosis. This
technique really implies that the autograft should have a
remaining notch if the distal anastomosis is to be
performed without risk of distortion. The technique was
changed and the left ostium was dissected from the aortic
wall and reimplanted in the autograft. The autograft was
given a straight rather than an undulating finish, facilitating
anastomosis and safer recreation of the sinotubular junction.

In almost half of our patients (25 out of 53) the aortic root
(the aortic anulus and/or the ascending aorta) required modi-
fications to match the autograft. Other investigators have
also recommended annuloplasty for correction of aortic
anulus dilatation and reduction of larger aortic sinotubular
junctions compared to the autograft, and we fully agree
[4,10,11].

One must bear in mind that only by focusing on the
problem of early autograft incompetence can we achieve
an improvement, and the improvement may only reflect
the surgeon’s learning curve for this procedure. Despite
this, we feel that changing the strategy has been beneficial
to our results.

5. Conclusion

Early aortic insufficiency after the Ross procedure can be
minimized by patient selection, intraoperative correction
of anatomical mismatch and an improved surgical technique.

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