Pediatric tracheal reconstruction with pericardial patch and strips of autologous cartilage

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Abstract

Objective: To analyze the results of pediatric tracheal reconstruction with autologous pericardial patch and strips of cartilage. Methods: From September 2003 to February 2008 14 non-consecutive children were operated using pericardial patch augmentation of the trachea combined with external reinforcement with strips of autologous cartilage. Thin semicircular strips were fashioned from costal arch cartilage. Associated vascular rings, slings and aberrantly coursing arteries were treated first. Cardiopulmonary bypass was used in all. Intraoperative tracheobronchoscopy was done in all. Postoperative bronchoscopies were performed at different time points. A retrospective analysis of patient records, surgical reports, tracheobronchoscopies, echocardiographic studies and CT scans was performed. Pre- and postoperative tracheal cross-sectional areas were digitally measured and compared to cricoid cross-sectional areas in six patients. A paired t-test was used to make comparisons. Results: Median age at operation was 21.3 (range 2.5–85) months. Ten patients were female. Four had associated surgery for cardiac anomalies. Double aortic arch (8), pulmonary artery sling (2), and aberrant origin of brachiocephalic artery (1) were concomitantly treated. Two patients had pulmonary agenesis. One patient had stenosis due to systemic inflammatory disease. Median follow-up was 27 (1–53) months. Late mortality occurred in one patient with pulmonary agenesis. One patient was reoperated and two bronchoscopies were done to remove granulation tissue. Median postoperative ventilation time was 5.5 (3–12) days with the exception of patients with pulmonary agenesis. Mean preoperative cross-sectional area was 29.4 \( \pm \) 22.5% of the lumen at cricoid level. At last bronchoscopy this had increased to 65.0 \( \pm \) 12.5% (\( p = 0.0001 \)). To evaluate the stability of the reconstructed trachea, we compared the mean luminal areas at inspiration and expiration. No difference was observed (\( p = 0.13 \)). One patient remains with mild stridor at exercise; all others have no respiratory symptoms. Conclusion: A stable wide trachea can be obtained in the great majority of cases, including whole length tracheal obstructions with complete circular rings. The technique is safe and reproducible with short intensive care stay and good mid-term results. Growth of the reconstructed trachea appears to be unrestricted.

Keywords: Trachea; Pediatric; Surgery

1. Introduction

Relief of pediatric tracheal stenosis is usually difficult with the rare exception of localized short segment obstruction where resection and end-to-end anastomosis can be performed. In the majority of patients the trachea is stenosed over a longer segment while tracheobronchial malacia and complete circular tracheal rings may be present. Many different procedures have been described for relief of long segment obstruction but the ideal and universally applicable technique has not been found yet. We describe here the results that were obtained with a technique that augments the trachea with a pericardial patch while at the same time providing sufficient tracheal stability by placement of multiple semicircular strips of autologous cartilage around the reconstructed area.

2. Materials and methods

From September 2003 to February 2008 14 non-consecutive children with tracheal stenosis were operated using a technique of pericardial patch augmentation of the trachea combined to external tracheal reinforcement with strips of autologous cartilage.
A retrospective analysis of patient records, surgical reports, tracheobronchoscopic reports, echocardiographic studies and CT scans was performed. The study was approved by the institutional ethics committee.

The preoperative diagnostic protocol included CT scan and rigid and/or flexible tracheobronchoscopy to analyze the length and severity of the obstruction as well as the anatomy of potentially co-existing vascular anomalies. Tracheobronchial malacia and presence of circular tracheal rings were documented. Preoperative echocardiography was done in all patients to detect and evaluate cardiovascular defects.

Vascular rings, slings and aberrantly coursing arteries were surgically treated in order to avoid any remaining compression of trachea, main bronchi and esophagus.

2.1. Surgical technique

A median sternotomy was performed in all patients without the need of extending the skin incision cranial to the sternum. After opening the pericardium vascular structures were identified and mobilized. The anterior surface of the trachea was dissected free cranial to the aortic arch and then cleaned to the proximal main bronchi. Care was taken to avoid damage to tracheal vascularization and no intent was made to free more than the anterior surface of trachea and main bronchi. Rings, slings and aberrant arteries were repaired first, with the use of cardiopulmonary bypass if necessary. A ductal ligament or patent arterial duct was always divided. In double aortic arch the smaller left sided arch was divided and tracheal compression by the right-sided aortic arch was relieved by traction on the arch moving it away from the trachea. In one patient a smaller right arch was divided. In pulmonary artery sling the left pulmonary artery was withdrawn from its abnormal position between trachea and esophagus and then orthotopically reanastomosed to the main pulmonary artery. An anomalous origin of the brachiocephalic artery was corrected by reattaching the artery more proximally on the aortic arch or on the left carotid artery if deemed necessary. Hereafter, the tracheal obstruction was re-evaluated intraoperatively by bronchoscopy. If relief of tracheal stenosis was observed to be insufficient tracheal surgery was performed.

For tracheal repair mild hypothermic cardiopulmonary bypass with beating heart was used in all patients. The narrowed segment of the trachea was opened in a longitudinal fashion and this incision was extended in both directions to a point where the tracheal diameter was considered to be normal. In most patients the distal part of the incision extended into the tracheal bifurcation. The exact position of the longitudinal incision in the trachea was both guided by intraoperative bronchoscopy and macroscopic appearance at surgery. Normally the trachea was opened in the midline but in some patients a more lateral placement of the vertical incision was chosen when the trachea was compressed in an anteroposterior direction. In these cases a sharp angled curvature of the tracheal wall could be present, indicating a better postoperative result if the enlargement patch was positioned in a more lateral location where the angle was most sharply bending. The endotracheal tube was withdrawn for some distance if necessary. Two (3—5 F) Fogarty arterial embolectomy catheters (Edwards Lifesciences, Irvine, CA, USA) were inserted into both main bronchi to avoid the entrance of blood. A patch of autologous pericardium was harvested and cleaned. The width of the patch was made in such a way that the diameter of the reconstructed trachea would be slightly oversized. A continuous suture of 5—0 or 6—0 PDS (Ethicon Inc., Piscataway, NJ, USA) was used to suture the patch. Care was taken to avoid passing the needle through the mucosa. Before cardiopulmonary bypass was started a small segment of cartilage was taken from the anterior right costal arch by a 3 cm separate incision and fashioned into thin semicircular curved strips with sufficient rigidity. The strips can be shaved out of the costal arch cartilage thus avoiding any loose and sharp ends. The strips were made as thin as possible while maintaining an adequate rigidity. Strips were typically 2.5—3 mm wide and 2 mm high. The length depended on the size of the trachea. Strips were first attached to both edges of the divided tracheal rings maintaining the correct curvature (Fig. 1). With one or more additional sutures the strips were then attached to the pericardial patch stabilizing it and lifting it up (Fig. 2). Negative pressure was applied to the endotracheal tube to control the stability of the reconstruction. Collapse of the reconstructed trachea typically meant that one or two more cartilage strips had to be added to the reconstruction. Air leaks were sought for by immersion of the operated trachea in a Ringers solution. The endotracheal tube was left in a normal position which was many times halfway down the reconstructed segment.

All patients were sedated and ventilated for at least 3 days before extubation was considered.
2.2. Tracheobronchoscopy

Perioperative tracheobronchoscopy was performed in all patients after induction of anesthesia and repeated after relief of tracheal compression by surgical division or rerouting of vascular rings, slings or aberrant arteries to evaluate the remaining stenosis. This protocol is used in all patients who undergo surgery for tracheal obstruction. If obstruction is caused by a vascular ring or sling, or by aberrant origin or course of an artery, division or rerouting of the responsible vascular structure may lead to satisfactory relief of the tracheal stenosis as then can be confirmed by repeat bronchoscopy. In the patients of this study the tracheal obstruction remained equal or did not decrease sufficiently after vascular surgery and tracheal surgery was necessary. Finally, bronchoscopy was performed again to control the result of the tracheal repair.

All bronchoscopies were recorded on tape or DVD and used for this study. The tapes and DVDs were converted to .avi or .mpg files. Images were studied independently by a researcher and an ENT specialist to evaluate the tracheal lumen (as percentage of the lumen at the cricoid) at the level of the (previous) obstruction at both in- and expiration. Only bronchoscopies with the patient spontaneously breathing were used for evaluation of the tracheal lumen after surgery.

2.3. Follow-up

Duration of pre- and postoperative intensive care stay and time of mechanical ventilation were recorded.

Patients were evaluated by flexible or rigid bronchoscopies at several time points after surgery: in the operating theatre directly after repair, at the moment of extubation, and at later stages to control the surgical reconstruction or if deemed necessary by recurring or remaining symptoms. It was rare to have tracheobronchoscopies performed later than 6 months following surgery, the main reason being that it can be difficult to convince parents to perform bronchoscopy in a completely asymptomatic child. Furthermore, these repeat bronchoscopies may only serve a scientific purpose.

Cross-sectional area was used to define the remaining lumen of the operated trachea. Tracheal diameter was less informative as some tracheas had more oval than circular lumina. Evaluating the narrowest cross-sectional tracheal surface area was done by comparing the narrowest area to the cross-sectional area at the level of the cricoid.

When the tracheal lumen slowly tapered towards a narrower segment comparison of the smallest area to the cricoid cross-sectional area was sometimes difficult. In these cases an additional method was used to measure the narrowest tracheal lumen. This was done by means of the biggest bronchoscope that could pass the smallest part of the trachea. In the medical records the scope sizes were noted. The diameter of the biggest size of scope that could pass the stenosis was divided by 2, squared and multiplied by \( \pi \). The resulting surface area was then compared to the area at cricoid level.

This method of evaluation gives an accurate percentage of lumen; all stenoses were evaluated both at an average inspiration and at an average expiration. The evaluation process was done twice independently by two observers with a time gap of two months in between. Estimations that differed more than 10% were re-evaluated. In- and expiratory measurements were averaged to be able to compare cross-sectional areas before surgery and at moment of last follow-up.

2.4. Clinical condition

Clinical condition was evaluated with specific attention to weight gain, problems with feeding, respiratory stridor or other respiratory symptoms at last follow-up. Weight gain was recorded and compared to normalized age/weight lists.

2.5. Statistical analysis

SPSS 14.0 for Windows was used for statistical analysis (SPSS Inc., Chicago, IL, USA). The following data were imported into SPSS: age and weight at operation, the number of days of admission to the pediatric intensive care unit, the number of days of ventilation, both before and after tracheal surgery, cardiopulmonary bypass time and the tracheal lumina as recorded before and after the operation. Descriptive statistics with median and range were used to report the results.

The in- and expiratory tracheal luminal areas were compared by a paired \( t \)-test. In- and expiratory data were put together, separated in the following time points: preoperatively, and at last bronchoscopy during follow-up. The means of the time points described above were compared using a paired samples \( t \)-test.

3. Results

3.1. Diagnosis and surgery

From September 2003 to February 2008 14 non-consecutive children had relief of tracheal obstruction by our technique (Table 1). The median age at operation was 21.3 (range 2.5—85) months. Ten patients were female. The median weight at operation was 7.0 (range 2.9—22.5) kg.
Four patients had associated cardiac anomalies: right atrial isomerism with VSD, left isomerism with complete AVSD, multiple VSDs, and secundum type ASD.

A vascular ring, sling or anomalous arterial origin was present in 11 patients: double aortic arch (8), pulmonary artery sling (2), and aberrant origin of brachiocephalic artery in one (Figs. 3 and 4). In patients with double aortic arch the right arch was hypoplastic in one (patient 3), all others had a hypoplastic left arch. In two double arches (patients 3 and 14) tracheal compression was additionally caused by a carotid artery that crossed the anterior aspect of the trachea. One patient (6) with pulmonary artery sling had long-segment tracheal stenosis with all complete circular rings while the other patient with pulmonary artery sling (10) had near complete circular rings.

Two patients (4, 12) had been operated previously (division of double aortic arch; VSD closure), all others had no history of previous surgery.

Pulmonary agenesis and congenital long segment tracheal stenosis were present in two patients (5, 8). Pulmonary agenesis was right-sided in one patient with associated complete AVSD and left-sided in another patient with multiple VSDs (Fig. 5).

<table>
<thead>
<tr>
<th>Patient</th>
<th>Sex</th>
<th>Age at surgery (months)</th>
<th>Syndrome</th>
<th>Tracheal obstruction</th>
<th>Vascular anomalies</th>
<th>Cardiac anomalies</th>
<th>Previous surgery</th>
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<td>1</td>
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<tr>
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<td>F</td>
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<td>Double arch</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>3.3</td>
<td>—</td>
<td>Laterally compressed tracheal arches</td>
<td>Double arch; aberrant carotid artery</td>
<td>—</td>
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</tr>
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<td>4</td>
<td>F</td>
<td>11.8</td>
<td>—</td>
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<td>Double arch</td>
<td>—</td>
<td>Division left aortic arch</td>
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<td>5</td>
<td>F</td>
<td>2.5</td>
<td>—</td>
<td>Long segment, all circular rings; right pulmonary agenesis</td>
<td>—</td>
<td>cAVSD; left isomerism</td>
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<td>6</td>
<td>F</td>
<td>85</td>
<td>—</td>
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<td>PA sling</td>
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<tr>
<td>7</td>
<td>F</td>
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<td>Double arch</td>
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<tr>
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<td>4.5</td>
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<td>Multiple VSDs</td>
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<td>F</td>
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<td>F</td>
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<td>—</td>
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<td>PA sling</td>
<td>ASD</td>
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<tr>
<td>11</td>
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<td>4.5</td>
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<td>Double arch</td>
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<tr>
<td>12</td>
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<td>5.5</td>
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<td>Double arch</td>
<td>Right atrial isomerism; VSD</td>
<td>Closure of VSD and patent duct</td>
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<tr>
<td>13</td>
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<td>Sagittally compressed tracheal arches</td>
<td>Aberrant brachiocephalic artery</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>14</td>
<td>M</td>
<td>4.5</td>
<td>—</td>
<td>Long segment, compressed tracheal arches</td>
<td>Double arch; aberrant carotid artery</td>
<td>—</td>
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</tr>
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ASD: atrial septal defect; VSD: ventricular septal defect; cAVSD: complete atrioventricular septal defect; PA: pulmonary artery.

Fig. 3. Tracheal stenosis with double aortic arch.

Fig. 4. Bronchoscopic appearance of bilateral tracheal compression by double aortic arch.
One patient (1) had no cardiovascular anomalies. His tracheal obstruction was the result of an incompletely understood systemic inflammatory disease that had led to severe tracheal scarring and deformation.

Eleven patients received 2–4 strips of cartilage to stabilize the widened trachea. Four patients (5, 6, 8, 10) with long-segment tracheal stenosis and circular rings received 6–8 cartilage strips. The length of the tracheal reconstruction ranged from 3 to 7 cm. Median cardiopulmonary bypass time was 101 (range 41–237) min.

All vascular rings, slings and other vascular aberrations with tracheal compression were treated as described above. Pulmonary artery banding was associated to tracheal repair in the patients (5, 8) with complete AVSD and multiple VSDs. A secundum type ASD was closed concomitantly in patient 10.

3.2. Follow-up

Late mortality occurred in one patient (patient 5) with pulmonary agenesis, long segment tracheal obstruction and complete AVSD. This patient had a long and difficult postoperative course with a tracheal sliding repair of the transition of trachea to left main bronchus 3.2 months after the first procedure. Three months later debanding and AVSD repair was performed after which a tracheal cannula was inserted. Mortality occurred 8.2 months after initial tracheal repair and was caused by obstructive tracheal granulation tissue distal to the tip of the tracheal cannula and concomitant bacterial sepsis. Pulmonary artery debanding was performed 2.5 years later in patient 8 when the VSDs had closed spontaneously.

One other patient (9) was reoperated, 1.7 months after tracheoplasty. The result of the initial operation was good and recovery was fast and uneventful but symptoms recurred and repeat bronchoscopy showed a right-sided lateral impression of the trachea with loss of luminal area. At reoperation it was observed that persistent pressure from the remaining right aortic arch was responsible for recurrent tracheal obstruction. A new tracheal reconstruction was performed using the same technique. The right-sided aortic arch was withdrawn from the trachea by aortopexy towards right lateral. Thereafter, tracheal obstruction did not recur.

Two patients (4, 12) had successful bronchoscopic removal of intraluminal depositions of fibrin and granulation tissue that caused respiratory symptoms. In the follow-up respiratory symptoms did not recur.

No problems were observed in both the sternotomy and the costal cartilage harvest wounds.

Four (4, 5, 8, 12) patients were on mechanical ventilation prior to surgery.

Except for patients 5 and 8, median postoperative intensive care stay was 7 (range 3–61) days. Median postoperative ventilation time was 5.5 (range 3–12) days.

Patients 5 and 8 with pulmonary agenesis, large left to right cardiac shunt and long-segment tracheal stenosis had longer intensive care stays. Patient 5 was admitted to the intensive care unit preoperatively for 76 days and postoperatively for 124 days. Patient 8 was admitted to ICU preoperatively for 51 days and postoperatively for 299 days. Both patients finally received a tracheal cannula because of inability to wean off mechanical ventilator. One patient (5) died later, the other patient (8) is doing well 2.5 years later.

Follow-up was complete in all patients. Median follow-up was 27 (range 1–53) months.

3.3. Analysis of tracheal lumina

The two patients with pulmonary agenesis were excluded from analysis of tracheal cross-sectional areas. In two cases parental consent for control bronchoscopy was denied. In two intubated and ventilated patients preoperative bronchoscopy data could not be used for reliable measurement of tracheal lumen. Two patients had a too short follow-up. Finally, complete measurement (reliable control bronchoscopies minimally 6 months or more after surgery) of tracheal lumen was possible in six patients.

Preoperative measurements showed an average lumen of 31.0 ± 17.9%. At the last bronchoscopy the average cross-sectional area at the most narrow point was 65.0 ± 12.5% of the luminal area at the level of the cricoid. This increase was significant (95% confidence interval (CI) 23.34–38.16; \( p < 0.001 \)). To evaluate the stability of the reconstructed trachea, we compared the mean luminal areas at inspiration to the mean luminal areas at expiration. No significant difference was observed (95% CI 1.54–9.54; \( p = 0.14 \)).

3.4. Clinical condition

The two patients (5, 8) with pulmonary agenesis were excluded from this analysis. At the moment of last follow-up all patients were operated at least 1 month earlier. The mean time between the initial tracheal repair surgery and the moment of last follow-up was 26.5 ± 18.5 months.

3.5. Feeding difficulty

Before surgery all patients had difficulties with feeding. Feeding had considerably improved or normalized in all patients at last follow-up.
appropriate curved form and growth potential but are arterial wall patches do have the desired rigidity, an lacks any rigidity and makes for un unstable reconstruction, to mold into the right shape, pericardium on the contrary and re-anastomosis technique, cartilage is rigid and difficult of insufficient size and is used in combination with a resection have different properties: autologous tracheal patch may be for the material that supports the patches. The use of strips of metal or Gore-Tex which can be placed on the outside of the reconstructed trachea has been reported earlier [5,6]. External supported patch repair techniques have thus been described earlier with good results. Nevertheless, these materials are non-autologous and do not have growth potential. Autologous trachea, costal cartilage, pericardium and arterial wall have all been reported as patch materials for tracheal reconstruction [1,2,7—11]. All these materials have different properties: autologous tracheal patch may be of insufficient size and is used in combination with a resection and re-anastomosis technique, cartilage is rigid and difficult to mold into the right shape, pericardium on the contrary lacks any rigidity and makes for an unstable reconstruction, arterial wall patches do have the desired rigidity, an appropriate curved form and growth potential but are difficult to obtain and make the risk of surgery higher [7—13]. We have chosen to combine two autologous materials for tracheal reconstruction: pericardium for its availability and ease of use and cartilage to provide stability to the reconstructed trachea. Autologous cartilage can be fashioned into thin semicircular strips that are both flexible and still remain with sufficient rigidity to prevent airway collapse. Harvesting these cartilage strips is done through a small incision over the anterior aspect of the costal arch where strips are peeled off the lowest cartilaginous part of the costal arch. We have not observed any complications at this additional incision. The growth potential of these cartilage strips is unknown and we believe that true growth may be impaired or absent. However they are used only to stabilize the pericardial patch and for that reason are not wider than the patch and typically they form no more than 30—40% of the tracheal circumference. This probably allows for circumferential growth of the reconstructed trachea. Although follow-up in this series is no longer than 5 years (the first child was operated at the age of 5 months) we have not found restriction to growth of the reconstructed trachea.

Tracheal reconstruction with autologous pericardium and cartilaginous strips is remarkably easy and reproducible. The technique can be used both for short and long tracheal obstructions but should not be used as a replacement for end-to-end anastomosis or sliding repair in relatively short segment narrowings. In three of our patients tracheal obstruction started directly under the cricoid and continued up to the bifurcation. In these cases the whole trachea consisted of circular rings and was very narrow. Although we have no experience with autologous tracheal patch repair we feel that it would be difficult if not impossible to reconstruct these tracheas in any other way than by patching and subsequent stabilization. An unobstructed and stable trachea could be obtained while still not having lost the ability to grow with time. In one of these patients (patient 5) a later sliding repair had to be done to correct a sharp bend at the end of the patch reconstruction and just proximal to the left main bronchus. It is therefore important to realize that our technique will not be able to fully correct acute curvatures in the airway. We have not used the technique in the main bronchi, mainly out of fear of damage to the smaller bronchi and to cause later scarring and loss of lumen. However, many of the reconstructions went up to the tracheal carina and we believe that main bronchus reconstruction may be feasible in older children when the diameter is sufficiently big to avoid late fibrosis and scarring.

Interference with tracheal blood supply is minimal as only the anterior surface of the trachea is dissected free. We believe this to be important but uninhibited growth after sliding repair (where more dissection is needed) has also been reported [14].

Tracheobronchial malacia was present in several of our patients and could be taken care of by our technique in the tracheal component but not in the bronchial malacia component. Serious expiratory infolding of the tracheal pars membranacea was observed sometimes during control bronchoscopies in the first few months after surgery, but collapse of the trachea itself was not observed. This phenomenon of infolding of the pars membranacea at expiration always disappeared with time. In theory, the strips of cartilage can be used to stabilize a malacic trachea and in fact we have successfully used this technique (without patch enlargement) in one 5-month-old infant with severe tracheomalacia without structural obstruction who could not be weaned off mechanical ventilation.

Most patients could be extubated within 1 week after the operation. The median time to extubation was 5.5 days which was much shorter than we had experienced in the past with other techniques. All patients could be weaned off the ventilator within 2 weeks with the exception of the two patients with pulmonary agenesis who both received a tracheotomy to facilitate weaning.

The reconstruction was generally observed to have become smooth and epithelialized within 3 months (Fig. 6). Granulation tissue was not a major problem in our series. Only in two patients granulation tissue or fibrin

### 3.6. Weight gain

No significant effect on weight gain could be obtained. Both preoperatively and during follow-up patients’ weights were in a range normal for age.

### 3.7. Respiratory distress

Only one patient remained with a mild stridor on exertion. Other signs of respiratory distress such as moments of acute dyspnea had disappeared completely after surgery in all patients.

### 4. Discussion

Many different techniques have been reported to reconstruct a narrowed trachea. If the length of the narrow segment is relatively short the obstruction can be resected and tracheal repair is by end-to-end anastomosis. Longer segments can be repaired either by a sliding type of repair or by a patch enlargement technique [1—4]. Different patch materials may be used and it is preferable that patch material is made of autologous tissue as this has a lower infection risk and a potential for growth. The autologous nature of the material used in the operation is important insofar that in a not completely sterile operative field infection is easier induced when non-autologous materials remain in the wound. What applies for the patch is also true for the material that supports the patches. The use of strips of metal or Gore-Tex which can be placed on the outside of the reconstructed trachea has been reported earlier [5,6]. External supported patch repair techniques have thus been described earlier with good results. Nevertheless, these materials are non-autologous and do not have growth potential. Autologous trachea, costal cartilage, pericardium and arterial wall have all been reported as patch materials for tracheal reconstruction [1,2,7—11]. All these materials have different properties: autologous tracheal patch may be of insufficient size and is used in combination with a resection and re-anastomosis technique, cartilage is rigid and difficult to mold into the right shape, pericardium on the contrary lacks any rigidity and makes for an unstable reconstruction, arterial wall patches do have the desired rigidity, an appropriate curved form and growth potential but are difficult to obtain and make the risk of surgery higher [7—13].
Deposition prompted bronchoscopic removal. Short duration of ventilatory support may be an explanation therefore as irritation of the tracheal mucosa by the endotracheal tube and suctioning catheters is limited. Granulation tissue formation has been reported following pericardial patch augmentation and cartilage patch repairs but also after sliding and tracheal autograft reconstructions [1,2,7–9,13,14]. Furthermore, shrinkage of the reconstructed trachea was not observed in our patients although in one patient the procedure had to be repeated within 2 months. A bulging right aortic arch had caused recurrent tracheal obstruction and we suspect that two cartilage strips had loosened. Recurrent stenosis has been reported in much higher incidences after unsupported periald patch augmentations [13].

Mortality occurred in one complex patient with pulmonary agenesis who had tracheal reconstruction, repeat sliding repair at the level of the left main bronchus and repair of complete AVSD. Despite tracheal cannulation this patient could not be discharged from the intensive care unit and finally died of sepsis and tracheal obstruction due to granulation tissue forming at the tip of the tracheal cannula.

All patients were clinically well at last follow-up. A tracheal cannula was only needed in the two patients with pulmonary agenesis, although in both an adequately sized tracheal lumen had been obtained. We feel that the inability to wean from the ventilator in these two patients may have been due to an increased length of the trachea in pulmonary agenesis while one needed later a sliding repair of the distal trachea to correct for a sharp bending.

As tracheal obstruction in infancy is rare and complex we believe in a multidisciplinary team approach where the ENT surgeon should play a central role. The team should include dedicated members from the departments of pediatric cardiothoracic surgery, pediatric surgery, anesthesiology and intensive care [15].

Limitations of the study include the small number of patients and the follow-up time not being longer than 5 years. Patients were non-consecutive with a few other patients having sliding repairs in the study time interval. Evaluation of the tracheal lumen was done directly after correction or relief of the vascular anomalies and may not always have been completely objective. Furthermore, measurements of tracheal cross-sectional areas were not available in all patients and could be difficult and have a fault level of up to 10% [16,17]. Despite these possible shortcomings we feel that a stable and wide trachea can be obtained by our technique in the great majority of cases. The technique is safe and easily reproducible with good short- and mid-term results. Although not documented by imaging, growth of the reconstructed trachea appears clinically to be unrestricted.

References

Appendix A. Conference discussion

Dr J. Comas (Madrid, Spain): Congenital tracheal stenosis in infants has a variety of surgical alternatives. Your paper confirms the utility of the autologous pericardium patch enlargement with external reinforcement of the trachea using strips of autologous costal cartilage as was previously demonstrated by Idriss in 1984. However, this original technique was used in structural anatomic tracheal stenosis.

I have two questions related to the selection of your patients.

Reading your paper we have little information related to the previous clinical status. Only 4 patients were with ventilatory support. Also, it looks to me that the median age was nearly 2 years old and could you explain to us how you select the patients and confirm the indication, is the first one.

Also, 60% of your patients had mostly a functional tracheal stenosis due to extrinsic compression or tracheobronchial malacia. Why have you avoided the more conservative approach to these patients? Maybe an external vascular pexy with cartilage reinforcement would be enough. As you know, this is a literature controversy.

My last question is related to your patient No. 1. The indication was related to inflammatory stenosis. Could you give us some information of the evolution of the patient related to possible fibrosis in the pericardium suture area, and also if he had any additional medication.

Dr Koolbergen: To begin with your last question, this patient with systemic inflammatory disease was operated rather recently and he’s doing clinically well now, but we have not very long follow-up of this patient.

Regarding the clinical status of the other patients before surgery I can say that all patients came to us with severe respiratory problems. All had recurrent respiratory infections and inspiratory stridor. So it was symptoms they came with. And then evaluating the pathology, we found the tracheal stenosis in combination with the vascular anomalies.

Dr Comas: The key question is you have used this technique in functional tracheal stenosis mostly, 60% of the patients, and thus this technique is mostly in the repair for anatomic stenosis. The point is why you do that and you do not try first other possibilities before doing this technique?

Dr Koolbergen: Well, it’s just a technique we tried because it looked for us that it was more easy to apply in these cases. And, of course, you can do sliding tracheoplasty as well for this patient group. But this technique needs more extensive dissection of the complete trachea and therefore our technique has a theoretical advantage of less dissection and less impairment of tracheal blood supply.

Dr C. Schreiber (Munich, Germany): To add to Dr Comas’s question, I have never performed such surgery. In which cases would you advise us to go ahead and treat the trachea in such an aggressive way as you have described?

Dr Koolbergen: Of course, in short segment tracheal stenosis, you can simply do a resection and end-to-end anastomosis. But if the stenosis is longer, exceeding more than 3 cartilage rings, we think this can be a useful technique to overcome this problem.

Dr G. Sarris (Athens, Greece): Just on the same subject, it was not clear to me from the presentation did the patients, in your group have complete rings or normal trachea with external compression? And if so, I believe the question is whether these patients would have done very well anyway just by division of the ring and relief of the external compression without tracheal surgery at all? How do you decide then whether to do this procedure on the trachea itself instead of first relieving the obstruction and wait and see.

Dr Koolbergen: We first took care of relief of the tracheal compression, of course, and then we did intraoperative tracheoscopy. And if the relief of the tracheal compression was not enough, if the lumen was still less than, let’s say, 50%, we went on with this technique.

Dr Sarris: If I may continue on this line of thinking, over the same time period, did you treat a number of patients with a similar problem whose external compression relief was sufficient, so that tracheal surgery was not necessary, and what was the relative percentage?

Dr Koolbergen: There was only one patient where relief of external compression was enough. And we did not use the pericardial patch in this case, but only add some cartilage strips on the outside of the trachea, because usually it’s a combination of anatomical narrowing and tracheal malacia, of course, and then we reinforce the trachea at that point by the use of only cartilage strips.

Dr R. Pretre (Zurich, Switzerland): This means that for usual vascular ring, you would do a sternotomy on those patients.

Dr Koolbergen: Sorry?

Dr Pretre: For usual vascular ring, you would do a sternotomy?

Dr Koolbergen: Yes.

Dr Pretre: And you go ahead then with this plasty if the compression is not totally relieved?

Dr Koolbergen: Yes.