Epidemiology of chronic *Pseudomonas aeruginosa* infections in the airways of lung transplant recipients with cystic fibrosis

Absarct

**Background** – The source of airway colonisation with *Pseudomonas aeruginosa* is not well defined in patients with cystic fibrosis after lung transplantation. Using a DNA-based typing system a study was undertaken to investigate whether lung transplant recipients acquired new strains of *P aeruginosa* or retained those they had before transplantation.

**Methods** – Seventy four *P aeruginosa* isolates taken before and after transplantation were analysed from 11 patients with cystic fibrosis who had undergone lung transplantation in the Medical School of Hanover between 1988 and 1994. The genetic relatedness of the 74 *P aeruginosa* strains was evaluated from macrorestriction fragment pattern similarity.

**Results** – Each of the 11 lung transplant recipients harboured one identical *P aeruginosa* clone before and after transplantation. The airways of four of the 11 patients were preoperatively colonised by two or three different clones, but six months after transplantation only one clone was detectable.

**Conclusions** – These results show that there is no change in the *P aeruginosa* population in the airways of lung transplant recipients before and after transplantation and it is assumed that the chronic drainage of *P aeruginosa* into the allografts is caused by the bacterial reservoir in the paranasal sinuses and the trachea.

(Thorax 1997;52:318–321)

Keywords: lung transplantation, cystic fibrosis, *Pseudomonas aeruginosa*.

Double lung transplantation has become a recognised and established treatment for adults and children in terminal respiratory failure resulting from cystic fibrosis. One of the major problems in the early postoperative period is infectious bronchopulmonary complications caused by viruses, bacteria, and fungi.1 Although the cystic fibrosis specific epithelial membrane defect does not recur in lung transplants,2 it seems that the upper airways, particularly the sinuses and the trachea, remain a bacterial reservoir after surgery.34 Using macrorestriction fragment pattern analysis as a DNA-based typing system we investigated whether lung transplant recipients in our clinic infected with *Pseudomonas aeruginosa* acquired new strains or retained their strains which they harboured before lung transplantation. The results might have direct implications for the clinical and perioperative management.

A previous study by Tsang et al5 showed that three of the four lung transplant recipients with cystic fibrosis who harboured *P aeruginosa* were colonised postoperatively by genotypes which were different from those carried before the transplantation. Only in one transplant recipient with cystic fibrosis were the preoperative and postoperative isolates identical. Analysis of the origin of *Burkholderia cepacia* infection after lung transplantation in patients with cystic fibrosis indicated that the upper airways could be a source of bacterial colonisation or reinfection of the lung allografts.6

**Methods**

**Patient Population, Bronchoalveolar Lavage, and Bacterial Strains**

*P aeruginosa* strains were isolated from 11 lung transplant recipients with cystic fibrosis (five men) of mean age 28.8 years (range 23.5–32.1) who had undergone lung transplantation in the Medical School of Hanover between 1988 and 1994 (table 1). With the exception of patient 2 who had a heart-lung transplant, all other patients received bilateral lung transplantation with bronchial anastomosis. All patients were colonised before and after lung transplantation with *P aeruginosa*.

Preoperative isolates were retrieved from sputum samples and postoperative isolates from bronchoalveolar lavage (BAL) fluid. Sputum samples were homogenised by vortexing with sterile glass beads for one minute. An aliquot was diluted 1:1000 in phosphate buffer saline (PBS). Undiluted and diluted specimens (50 μl each) were plated onto Columbia blood agar (Unipath, Wesel, Germany), MacConkey agar (Unipath), and chocolate agar (Unipath). BAL fluid samples were taken by fibroptic bronchoscopy from the middle lobe. After placing the bronchoscope in a wedge position, six aliquots of 0.9% (w/v) sodium chloride solution (20 ml each) were instilled into segment 4 or 5. The recovery of the first aliquot was discarded to make sure that the lavage was taken from the alveolar compartment rather than the small airways. The mean recovery rate was 55%. Seventy four isolates of *P aeruginosa* with different phenotypes one week before, one week

---

**Acknowledgments**

Siegbert Walter, Peter Gudowius, Jutta Boßhammer, Ute Römling, Hartmut Weißbrodt, Wolfgang Schürmann, Horst von der Hardt, Burkhard Tümmler

---

**Key Words**

Lung Transplantation, Cystic Fibrosis, Pseudomonas aeruginosa

---

**Correspondence to:** Dr S Walter, Zentrum Medizinische Hochschule Hannover, Gegenstrasse 100, D-30623 Hannover, Germany

---

**Received 11 June 1996**

**Returned to authors 23 September 1996**

**Revised version received 14 November 1996**

**Accepted for publication 19 November 1996**
after, and six months after transplantation were characterised by macrorestriction analysis. Based on the results in previous studies, the BAL fluid was considered to be not contaminated, or only marginally so, if the specimen contained <10^5 colony forming units (CFU)/ml of oropharyngeal flora, no ciliated epithelial cells, and <1% squamous epithelial cells.7–9

MACRORESTRICTION ANALYSIS

The genotyping of the P. aeruginosa strains was carried out as described previously.10 Briefly, the agarose-embedded P. aeruginosa DNA was digested by Spe I and the resulting fragments were separated using a CHEF DRII or CHEF DRIII apparatus (BioRad, Richmond, California, USA). Running conditions in 1% agarose gels were electric field strength 6 V/cm, linear ramping 5–25 seconds for 20 hours and 5–60 seconds for 17 hours in 0.5 × Tris-borate-EDTA (TBE) buffer. λ BstEII digest, λ phage DNA oligomers, Spe I digested P. aeruginosa C,11 and PAO (DSM 1707) were used as size markers and restriction digestion fingerprints of reference strains. Fragment patterns on the same gel were compared visually side by side. The relatedness of patterns of the strains was then evaluated by computerised cluster analysis.10 Two P. aeruginosa isolates are members of a clonal lineage if they share >75% of Spe I bands.10 Of the isolates from a specimen of sputum or BAL fluid with identical Spe I fragment patterns, one representative strain was selected for a second macrorestriction analysis. In total, 33 isolates were rerun to ascertain the pairwise fragment pattern similarity in quantitative terms. Clones and clonal variants that were identical were indicated with the same letters.

Results

MICROBIOLOGICAL RESULTS

The genotyping indicated that each of the 11 lung transplant recipients harboured at least one identical clone or a clonal variant of a P. aeruginosa strain preoperatively and postoperatively but each patient harboured a different clone (table 2). Two of the 11 patients were preoperatively colonised with three different genotypes. One week after transplantation one of these was colonised with two different and the other with only one genotype. Six months after transplantation only one clone persisted in each of these patients. Of the two patients who were carrying two different genotypes before transplantation, one harboured two different clones one week after transplantation and the other retained only a single strain. Six months after transplantation only one genotype was isolated in the airways of both patients (fig 1). The isolates of P. aeruginosa of the lung transplant recipients after lung transplantation were mostly mucoid LPS-rough strains specific for chronic respiratory infections of patients with cystic fibrosis.12 They did not change their cystic fibrosis specific morphology in the lung allografts.

CLINICAL RESULTS

Clinical characteristics of the studied patients are summarised in table 1. Cystic fibrosis was diagnosed at a mean age of 8.6 years (range 9 months to 19 years). The mean age at onset of the chronic P. aeruginosa infection was 15.7 years (range 9–21) and at lung transplantation it was 23.5 years (range 19–30).

The Cooper index12,13 was used as a standardised method for assessing functional results after lung transplantation. In this staging system four grades of bronchiolitis obliterans syndrome (BOS), with (a) or without (b) histo-

Table 1 Clinical characteristics of lung transplant recipients with cystic fibrosis (CF)

<table>
<thead>
<tr>
<th>Patient no.</th>
<th>Sex</th>
<th>Age at diagnosis of CF</th>
<th>CFTR genotype</th>
<th>Age at onset of chronic P. aeruginosa infection (years)</th>
<th>Age at transplantation (years)</th>
<th>First P. aeruginosa infection after transplantation (days)</th>
<th>No. of P. aeruginosa infections after transplantation</th>
<th>Cooper index</th>
<th>Survival time after transplantation (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>5 years</td>
<td>Rare unknown</td>
<td>21</td>
<td>21</td>
<td>30</td>
<td>1</td>
<td>BOS 0a</td>
<td>438</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>2 years</td>
<td>dF508/dF508</td>
<td>9</td>
<td>22</td>
<td>1431</td>
<td>2</td>
<td>BOS 0a</td>
<td>2643</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>12 years</td>
<td>dF508/dF508</td>
<td>17</td>
<td>21</td>
<td>0</td>
<td>0</td>
<td>BOS 0a</td>
<td>462</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>10 months</td>
<td>dF508/R551X</td>
<td>12</td>
<td>30</td>
<td>136</td>
<td>4</td>
<td>BOS 2a</td>
<td>746</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>12 years</td>
<td>dF508/2789 + S-G-A</td>
<td>18</td>
<td>25</td>
<td>0</td>
<td>0</td>
<td>BOS 0a</td>
<td>1319</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>12 years</td>
<td>dF508/12</td>
<td>13</td>
<td>21</td>
<td>145</td>
<td>3</td>
<td>BOS 2a</td>
<td>1604</td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>12 years</td>
<td>dF508/DF08</td>
<td>18</td>
<td>28</td>
<td>687</td>
<td>2</td>
<td>BOS 2b</td>
<td>1312</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>9 months</td>
<td>dF508/unknown</td>
<td>17</td>
<td>21</td>
<td>0</td>
<td>0</td>
<td>BOS 0a</td>
<td>1512</td>
</tr>
<tr>
<td>9</td>
<td>F</td>
<td>12 years</td>
<td>dF508/DF08</td>
<td>15</td>
<td>23</td>
<td>317</td>
<td>4</td>
<td>BOS 0a</td>
<td>1359</td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>19 years</td>
<td>dF508/DF08</td>
<td>19</td>
<td>27</td>
<td>0</td>
<td>0</td>
<td>BOS 0a</td>
<td>1321</td>
</tr>
<tr>
<td>11</td>
<td>F</td>
<td>10 months</td>
<td>dF508/2184insA</td>
<td>14</td>
<td>19</td>
<td>795</td>
<td>3</td>
<td>BOS 3b</td>
<td>1452</td>
</tr>
</tbody>
</table>

Cooper index: BOS = bronchiolitis obliterans syndrome; stages 0 = no abnormality, 1 = mild, 2 = moderate, 3 = severe; subcategory a = absence of pathological evidence of bronchiolitis obliterans; b = presence of bronchiolitis obliterans pathologically.12

1 Referring to 28 February 1996.
2 Deceased.

Table 2 Molecular epidemiology of Pseudomonas aeruginosa in lung allografts of lung transplant recipients with cystic fibrosis

<table>
<thead>
<tr>
<th>Patient no.</th>
<th>Before transplantation</th>
<th>After transplantation</th>
<th>Six months after transplantation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ab, ac, ad</td>
<td>ab, ac</td>
<td>ab</td>
</tr>
<tr>
<td>2</td>
<td>C, af, ag</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>3</td>
<td>ah</td>
<td>ah</td>
<td>ah</td>
</tr>
<tr>
<td>4</td>
<td>ai</td>
<td>ai</td>
<td>ai</td>
</tr>
<tr>
<td>5</td>
<td>aj</td>
<td>aj</td>
<td>aj</td>
</tr>
<tr>
<td>6</td>
<td>ah</td>
<td>ak</td>
<td>ak</td>
</tr>
<tr>
<td>7</td>
<td>al, am, al, am</td>
<td>al</td>
<td>al</td>
</tr>
<tr>
<td>8</td>
<td>an</td>
<td>an</td>
<td>an</td>
</tr>
<tr>
<td>9</td>
<td>ao, ap, ao</td>
<td>ao</td>
<td>ao</td>
</tr>
<tr>
<td>10</td>
<td>aq</td>
<td>aq</td>
<td>aq</td>
</tr>
<tr>
<td>11</td>
<td>ar</td>
<td>ar</td>
<td>ar</td>
</tr>
</tbody>
</table>

1 Sputum or throat swab; 2 Bronchoalveolar lavage fluid.
* Clones and clonal variants already identified in recent studies are indicated with the same capital letter. Novel genotypes were given two small letters.
Walter, Gudowius, Boûhammer, Römling, Weiûbrodt, SchuÈrmann, et al

Lung transplantation or combined heart-lung transplantation has emerged as a therapeutic intervention for cystic fibrosis patients with end-stage respiratory failure. Undoubtedly, lung transplantation improves the quality of life of most of the patients and all efforts should be made to optimise this treatment.

Our genotype analysis shows that all 11 lung transplant recipients harboured different *P. aeruginosa* strains, but each of the patients remained colonised with the same strain as was cultured before lung transplantation. These results are in conflict with those of Tsang*et al* who used the pCMTox probe for strain typing. This probe recognises restriction fragment length polymorphisms in a region of high genomic variability (T Heuer, personal communication) and it is tempting to assume that the shift of the habitat by transplantation is associated with genome rearrangements in the *P. aeruginosa* clone. Hence, a probe such as pCMTox which scans a single hypervariable locus may indicate a change, whereas the global genome-wide fragment pattern may undergo no or minor shifts.

Our genotype data support the hypothesis that a reservoir of *P. aeruginosa* remains in patients with cystic fibrosis who undergo lung transplantation, presumably in the upper respiratory tract or trachea. Recolonisation by these potentially multiresistant pathogens may cause infectious complications of the lung allografts and, combined with the impaired mucociliary clearance after lung transplantation and the immunosuppression, this creates a high risk of graft infection following lung transplantation. Some transplantation groups therefore recommend surgical drainage of the sinuses before transplantation, while other centres prescribe lifelong inhalation of antimicrobial agents to reduce the risk of re-infection or colonisation with *P. aeruginosa* from the upper airways.

The Stanford group developed a management strategy which combined endoscopic surgery with an initial clindamycin intravenous antibiotic treatment course and serial long term monthly sinus antimicrobial lavage. They reduced the need for reoperation for chronic sinusitis and reported that eight long term survivors required only one seven-day admission to hospital and parenteral antimicrobial agents against *P. aeruginosa* infections during a follow up period of 3200 days after lung transplantation. Davidson*et al* introduced a similar protocol in which sinus surgery was followed by daily saline nasal irrigation with fluid containing tobramycin. With this regimen the spectrum of all patients with cystic fibrosis who had undergone lung transplantation was free of *P. aeruginosa* and bacterial pneumonia was not reported. The Harefield group prescribed lung transplant recipients with a lifelong inhalation containing colistin sulphate via a face mask at a dose of 1 mega unit twice a day in the first three postoperative months reduced thereafter to 1 mega unit daily.

In spite of these measures, and an additional course with anti-pseudomonal antibiotics for the first 10

### Table 1

<table>
<thead>
<tr>
<th>Patient</th>
<th>Genotype</th>
<th>Lanes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pat. 1</td>
<td>ad (p)</td>
<td>4-9</td>
</tr>
<tr>
<td>Pat. 2</td>
<td>ab (p)</td>
<td>7-9</td>
</tr>
<tr>
<td>Pat. 3</td>
<td>ah (p)</td>
<td>5-6</td>
</tr>
<tr>
<td>Pat. 4</td>
<td>ai (p)</td>
<td>15-16</td>
</tr>
<tr>
<td>Pat. 5</td>
<td>aj (p, po, sma)</td>
<td>24-26</td>
</tr>
</tbody>
</table>

#### Figure 1
Genotyping of *Pseudomonas aeruginosa* isolates of five of the 11 lung transplant recipients with cystic fibrosis. SpeI fragment patterns of patient strains: one week before (p), one week after (po), and six months after transplantation (sma); lanes 4-14, 18-26. Lanes 1, 15, 29: Bst EII digests; lanes 2, 16, 28: oligomers; lanes 3, 27: SpeI digests of *P. aeruginosa* C (11) chromosome; lanes 17: SpeI digest of *P. aeruginosa* PAO (DSM 1707) chromosome. Genotypes of patient strains: lanes 4-9: patient 1, lane 4 ad (p), lanes 5-6 ac (p, po), lanes 7-9 ab (p, po, sma), lane 9 clonal variant of strain ab; lanes 10-14: patient 2, lane 10 af (p), lane 11 ag (p); lanes 12-14 C (p, po, sma), lane 13 clonal variant of strain C; lanes 18-20: patient 3, ah (p, po, sma), lane 18 clonal variant of strain ah; lanes 21-23: patient 4, ai (p, po, sma); lanes 24-26: patient 5: aj (p, po, sma), lane 24 clonal variant of strain aj.
Pseudomonas aeruginosa infections in lung transplant recipients with cystic fibrosis

postoperative days, the 79 lung transplant recipients studied had 43 P aeruginosa respiratory infections during the first three months after transplantation and 11 infections during each of months 4–6 and 7–12.

However, most lung transplantation groups do not carry out preoperative sinus surgery, either because they do not feel that sinus disease adversely affects the long term outcome of their patients or because of the complications involved in sinus surgery. Staumberger and Wolf, however, reported only two cases of cerebrospinal fluid rhinorrhea and no intracranial or ophthalmic complications in a series of over 4000 cases of functional sinus surgery.

As it is important to protect lung allografts from acquiring P aeruginosa from the upper airways, we plan to modify our perioperative management of lung transplant recipients. A prospective study is planned in which we will investigate whether sinus surgery combined with antimicrobial lavage or long term inhalation of nebulised antimicrobial agents via a face mask reduces the risk of postoperative infection in lung transplant recipients with cystic fibrosis.

We thank J Greipel for his help in the computerised cluster analysis and T Heuer for communication of unpublished analyses of genome plasticity of P aeruginosa. This work was supported by the Deutsche Forschungsgemeinschaft. SW is a fellow of the Walter-Marget-Vereinigung e.V.