Cross infection in a surgical ward caused by *Pseudomonas aeruginosa* with transferable resistance to gentamicin and tobramycin

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SUMMARY

An outbreak of gentamicin- and tobramycin-resistant *Pseudomonas aeruginosa* infection occurred in a surgical ward over a three-month period. Resistant *Ps. aeruginosa* strains with the same serological, phage, and pyocin type were cultured from the urine of six patients. Identical organisms were found on urine bottles, bedpans, and the hands of attendant staff. Inadequate disinfection played a major role in cross-infection. Isolates of the epidemic strain from each of the patients and of an unrelated but similarly resistant *Ps. aeruginosa* from one of them could transfer resistance to a recipient strain of *Ps. aeruginosa*. Resistance to gentamicin, kanamycin, tobramycin, sulphonamides, and mercuric chloride was determined by R factors belonging to *Pseudomonas* incompatibility group P-3. Aminoglycoside resistance was due to acetylation.

Urinary tract infection is the commonest type of hospital-acquired infection and is particularly associated with catheter drainage. Micro-organisms may enter through the lumen of the catheter or between the catheter and the wall of the urethra. *Pseudomonas aeruginosa* is a common aetiological agent, and owing to its pronounced resistance to antimicrobials the choice of an appropriate drug is limited. Gentamicin has a valuable place in therapy; the emergence of resistant strains is therefore important. Isolated reports of gentamicin-resistant strains of *Ps. aeruginosa* have been documented in the United Kingdom with no evidence of linked cases (Barnham et al., 1975; Eykyn and Phillips, 1975; Seal and Strangeways, 1975).

We report here a cross-infection of six patients with a strain of gentamicin- and tobramycin-resistant *Ps. aeruginosa*. All isolates were from urine specimens. Some of the patients had significant bacteriuria. The resistance was transferable to another strain of *Ps. aeruginosa*. The properties of the R plasmids involved were different from those previously isolated from *Ps. aeruginosa* in the United Kingdom.

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Patients

The outbreak occurred in a surgical ward. Six patients were affected from February to April 1975.

CASE 1

A 79-year-old man with benign hyperplasia of the prostate, admitted from another hospital on catheter drainage at the beginning of February 1975, had a urinary tract infection and septicaemia with a susceptible *Escherichia coli* which responded to gentamicin. Three weeks later he had a transurethral resection and was catheterised. After three days the catheter was removed and he was treated with co-trimoxazole blindly. A specimen of urine showed pyuria and significant (> 100 000 organisms/ml) bacteriuria with a strain of *Ps. aeruginosa* resistant to gentamicin, tobramycin, and carbenicillin (the epidemic strain). Two further specimens at 10-day intervals yielded the same strain. Treatment was with nalidixic acid, to which the strain was resistant. The patient’s condition improved, and he was discharged apparently well.

CASE 2

An 86-year-old woman had a partial resection of the bladder for a transitional cell carcinoma in 1971 for which cobalt therapy was given. She was admitted
in February 1975 for massive haematuria. After
cystoscopy under anaesthetic and bladder washout
she was catheterised. Ten days later the catheter
was removed. A sample of urine showed pyuria and
significant bacteriuria with \textit{E. coli}. In a subsequent
specimen the culture showed \textit{E. coli} and the epidemic
strain of \textit{Ps. aeruginosa} in significant numbers. A
further specimen, however, showed a pure growth of
\textit{E. coli}. No specific antimicrobial therapy was
given. She was transferred to another hospital for
cobalt therapy.

\textbf{CASE 3}
A 53-year-old man had an adenocarcinoma of the
prostate treated by orchidectomy and hormone and
deep \textit{x}-ray therapy in 1972. A left pyeloplasty was
performed and drainage established with a ureteric
catheter in November 1974. In January 1975 pus was
draining from the nephrostomy tube, so he was
admitted to hospital and treated with co-trimoxazole
empirically. Early in March the epidemic strain of
\textit{Ps. aeruginosa} was isolated from a ureteric specimen
of urine. Two further specimens yielded the same
strain. He was in severe renal failure and died shortly
afterwards.

\textbf{CASE 4}
A 56-year-old woman with a history of renal calculi
was admitted in March 1975 for investigation of
bilateral ureteric strictures. After cystoscopy and
right ureteric dilatation she was catheterised and
given co-trimoxazole prophylactically. Dilatation of
the left ureter was performed. A specimen showed
pyuria and significant bacteriuria with \textit{E. coli} and the
epidemic strain of \textit{Ps. aeruginosa}. This was not
-treated. She was discharged apparently well.

\textbf{CASE 5}
An 81-year-old man had arteriosclerotic dementia,
prostatism, and acute retention. He was catheterised
on admission in April 1975. A specimen showed
pyuria and significant bacteriuria with the epidemic
strain of \textit{Ps. aeruginosa}. No further specimens of
urine were received, and he was discharged well
without specific therapy.

\textbf{CASE 6}
A 57-year-old man was admitted with a history of
malignant neoplasm of the bladder and calculi in the
kidneys, bladder, and urethra. The calculi had been
removed and he had had deep \textit{x}-ray therapy. In
April 1975 he was admitted with acute retention and
catheterised. Three weeks later a specimen showed
pyuria and significant bacteriuria with the epidemic
strain of \textit{Ps. aeruginosa}. His condition deteriorated
and he died without specific therapy.

\textbf{Bacteriological investigations}

The strains were identified as \textit{Ps. aeruginosa} by their
criteria of Phillips (1969). Isolates from patients in
the ward over the previous three months as well as
those obtained in the epidemiological investigations
were typed by serology and bacteriophage sensitivity
at the Central Public Health Laboratory, Colindale,
London (Shooter \textit{et al.}, 1966). Active pyocin typing
(Govan and Gillies, 1969) was done in the Central
Microbiology Laboratory, Adelaide Hospital, Dublin.

In a bacteriological survey of the environment
samples were taken from drinking-water jugs, taps,
basins, sinks, baths, sluices, bedpans, urine bottles,
and a number of sites in sluice rooms and the ward
kitchen. In-use dilutions and stock solutions of
disinfectants were tested for concentration with a
comparator and cultured after neutralisation with
tryptone soya broth. Cultures were made from the
hands of attendant staff by a modification of the
technique of Bruun \textit{et al.} (1968). Faecal specimens
of the same staff were incubated in acetamide broth
and subcultured on to cetrimide agar (Brown and

Transmissibility of antibiotic resistance was
-tested by mating with PU21, an isoleucine-valine and
leucine-requiring streptomycin—and rifampicin-
resistant derivative of the PAO line of \textit{Ps. aeruginosa}
(Jacoby, 1974a). The recipient was pregrown at
43°C in an attempt to overcome the deoxyribonucleic
acid restriction system that operates in this organism
(Holloway, 1965). 10^8 cells/ml of potential donor and
recipient were mixed, incubated for about 18 hours
at 37°C, and spread on plates containing a selective
concentration of gentamicin (20 \(\mu\)g/ml), sulpha-
diazine (5 mg/ml), or tobramycin (10 \(\mu\)g/ml) and
rifampicin (100 \(\mu\)g/ml) to which the clinical strains
were sensitive for counterselection (Jacoby, 1974a).

Transconjugants were tested for resistance to
antibiotics by agar dilution (Jacoby, 1974a), mercuric
chloride, and ultraviolet light and for lysis by
bacteriophages B3, B39, C5, E79, F116, G101, M6,
and PB1, all of which propagate on R^- PU21
(Jacoby, 1974a). The ability to inhibit the fertility of
plasmid RP1 was tested by constructing strains
carrying RP1 and each of the new R plasmids. An
\textit{Fi}^+ (RP1) plasmid inhibits lysis by phages PRR1,
PRD1, PR3, and PR4 that normally propagate on
RP1-carrying strains (Stanisich, 1974; Jacoby, 1977).
Transfer proficiency was determined by
mating each PU21 \((R^+\) derivative with PU1 \((FP2^+
prototrophic) selecting for tobramycin-resistant
transconjugants. A \textit{Tra}^- plasmid is not self-
transmissible. \textit{Tra}^+ Pu21 (pM7) was also mated for
18 hours with \textit{E. coli} C selecting for transfer for
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gentamicin, tobramycin, or sulphonamide resistance.
Compatibility was tested by constructing strains carrying pMG7 and a second plasmid of known incompatibility specificity. The test plasmids and their Pseudomonas incompatibility groups were RP1 (P-1), R931 (P-2), Rip64 and R151 (P-3), R1162 (P-4), Rms163 (P-5), Rms149 (P-6), Rms148 (P-7), pRO271 (P-8), and R2 and R716 unclassified (Bryan et al., 1973; Bryan et al., 1974; Olsen and Hansen, 1976; Jacoby, 1977). Most crosses were performed with PU21 containing the test plasmid as donor and PAO303 (RP- arg-18) (Jacoby, 1974a) containing pMG7 as recipient. Twenty transconjugants were tested on antibiotic media selective for each plasmid individually to determine their ability to coexist with pMG7 except for crosses with R151 and R64 where phage resistance was scored, since the antibiotic resistance markers of these plasmids overlap those of pMG7.
Aminoglycoside acetylating activity was determined by the phosphocellulose-paper binding assay with 14C-acetyl coenzyme A as substrate (Haas et al., 1976). Assays were performed by Barbara Hoffman and Julian Davies at the University of Wisconsin, Madison, Wisconsin, USA.

Results

Patients 1 and 3 appeared to have a genuine infection. The epidemic strain was isolated once from each of the remaining four patients. The absence of follow-up specimens coupled with the poor urine collecting technique (see below) made it difficult to assess the significance of the isolates in cases 2, 4, 5, and 6. The organisms were resistant by disc sensitivity testing to carbenicillin, kanamycin, gentamicin, tobramycin, and sulphonamides. Colonial morphologies of the isolates were identical in all six patients in their unusual gelatinous consistency. The colonies were small, round, and glistening after 24 hours but became wrinkled on further incubation. Serological, bacteriophage, and pyocin typing reactions of the isolates from the six cases were identical (Table 1). No cultures of this type or colonial morphology had been isolated from the ward in the previous four years. Another strain (No. 1996) with identical resistance properties but a different typing reaction was also isolated from case 3.

The epidemiological survey was extensive but the resistant Pseudomonas was isolated only from bedpans and urine bottles. The latter were 'disinfected' in a solution of Hycolin. The 'in-use' concentration of this disinfectant was maintained in the ward at between 0.5% and 1%. No organisms were isolated from it. In error, however, this solution was further diluted by about 100-fold. Several isolates of Ps. aeruginosa were made from this diluted solution when in use. One isolation of Ps. fluorescens was also obtained from a jar steeping in this solution. Probably some of the urine specimens had been collected in unsterile containers before dispatch to the laboratory.

A nurse was found to be a carrier of the epidemic strain, which was isolated from her faeces on two occasions 10 days apart. A positive culture was also made from her hands. Sensitive strains of Pseudomonas were isolated from the faeces of another nurse and doctor. Cultures were made from the hands of attendant staff. Seven of them gave positive isolations for E. coli, Klebsiella, Proteus, Pseudomonas, and Enterococcus.

Isolates from each of the six cases and from a contaminated urine bottle could transmit multiple antibiotic resistance to a recipient strain of Ps. aeruginosa (Table 1). The frequency of transfer was only 10-7 to 10-8 per recipient. Transconjugants acquired resistance to gentamicin, kanamycin, tobramycin, and sulphonamides but not carbenicillin (Table 2). The non-epidemic strain No. 1996

<table>
<thead>
<tr>
<th>Strain No.</th>
<th>Source</th>
<th>Specimen</th>
<th>Typing reaction</th>
<th>Transmissibility of resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1771</td>
<td>Case 1</td>
<td>Urine</td>
<td>6e 6 109.1214</td>
<td>+</td>
</tr>
<tr>
<td>1775</td>
<td>Case 2</td>
<td>Urine</td>
<td>6e 6 109.1214</td>
<td>+</td>
</tr>
<tr>
<td>1881</td>
<td>Case 3</td>
<td>Urine</td>
<td>6e 6 109.1214</td>
<td>+</td>
</tr>
<tr>
<td>1996</td>
<td>Case 4</td>
<td>Urine</td>
<td>6e 6 109.1214(7)</td>
<td>+</td>
</tr>
<tr>
<td>1882</td>
<td>Case 5</td>
<td>Urine</td>
<td>6e 6 109.1214(7)</td>
<td>+</td>
</tr>
<tr>
<td>1922</td>
<td>Case 6</td>
<td>Urine</td>
<td>6e 6 109.1214(7)</td>
<td>+</td>
</tr>
<tr>
<td>1935</td>
<td>Bedpan</td>
<td>6e 6 109.1214(7)</td>
<td>Not tested</td>
<td></td>
</tr>
<tr>
<td>1936</td>
<td>Urine bottle</td>
<td>6e 6 109.1214(7)</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>1938</td>
<td>Nurse C</td>
<td>Faeces</td>
<td>6e 6 109.1214(7.44)</td>
<td>Not tested</td>
</tr>
</tbody>
</table>

AA = autoagglutinable. NT = non-typable.
transferred a similar plasmid. In addition to antibiotic resistance all the plasmids determined resistance to mercuric chloride and to the same subset of bacteriophages. The effect on phage propagation could be shown to be due to a new restriction and modification specificity introduced by the R plasmids (data not shown). Transconjugants from three of the eight donors were also resistant to ultraviolet light. All the R factors inhibited the fertility of plasmid RPl. Plasmid pMG7 was transmissible from PU21 to other strains of *Ps. aeruginosa* at a frequency of 10^{-5} to 10^{-6} but not to *E. coli*. The other plasmids were non-conjugative (Tra^-).

Compatibility testing showed that plasmid pMG7 could coexist stably with R plasmids belonging to Pseudomonas incompatibility groups P-1, P-2, P-4, P-5, P-6, P-7, and P-8 and with unclassified plasmids R2 and R716. Marked entry exclusion occurred with plasmid R151 and other P-3 group plasmids. Plasmids pMG7 and R151 were unable to coexist in the same host (Table 3), indicating that pMG7 belongs to the P-3 incompatibility group. Tra^- plasmids pMG8-14 gave similar incompatibility results.

By agar-dilution sensitivity testing all the plasmids from this outbreak gave enhanced resistance to gentamicin, kanamycin, sisomicin, and tobramycin. Data for pMG7 are shown in Table 4. Cell-free extracts of Pu1 (pMG7) were assayed for aminoglycoside inactivity enzymes. Aminoglycoside acetyltransferase activity was present. The spectrum of activity toward different substrates is shown in Table 5.

**Discussion**

Lapses in aseptic routine contributed to this outbreak of resistant *Ps. aeruginosa*. All the patients had been catheterised at some stage of their hospital stay. The system for continuous drainage was not a completely closed one since there was an inadequately closed outlet from the urine bag. Urine bottles and bedpans were sources of the epidemic strain. Even with proper sterilisation urine bottles and bedpans can be reservoirs of *Ps. aeruginosa* (McLeod, 1958). These had been inadequately disinfected. Contamination of disinfectants with pseudomonads is well recognised (Burdon and Whitby, 1967). There seemed to be confusion about the concentration of the disinfectant solutions issued to the ward in which the outbreak occurred. Simple boiling and storing dry was instituted. The isolation of faecal organisms, including the epidemic strain of *Ps. aeruginosa*, from the hands of attendant staff indicated that hand transmission may also have been important. The use of disinfectant was subsequently recommended for routine hand washing.

Although patients 1 and 3 appeared to have genuine urinary tract infections the outcome in each case was difficult to determine owing to the lack of routine follow-up urine specimens. It was clear that further specimens from patients 2, 4, 5, and 6 were

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**Table 2** Properties of R plasmids from resistant strains

<table>
<thead>
<tr>
<th>Strain No.</th>
<th>Source</th>
<th>Plasmid</th>
<th>Resistance phenotype</th>
<th>Fi (RPI)</th>
<th>Tra</th>
</tr>
</thead>
<tbody>
<tr>
<td>1771</td>
<td>Case 1</td>
<td>pMG7</td>
<td>Gm Km Tm Su</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>1775</td>
<td>Case 2</td>
<td>pMG8</td>
<td>Gm Km Tm Su</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>1811</td>
<td>Case 3</td>
<td>pMG9</td>
<td>Gm Km Tm Su</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>1996</td>
<td>Case 4</td>
<td>pMG10</td>
<td>Gm Km Tm Su</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>1881</td>
<td>Case 5</td>
<td>pMG11</td>
<td>Gm Km Tm Su</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>1882</td>
<td>Case 6</td>
<td>pMG12</td>
<td>Gm Km Tm Su</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>1936</td>
<td>Urine</td>
<td>pMG14</td>
<td>Gm Km Tm Su</td>
<td>R</td>
<td>R</td>
</tr>
</tbody>
</table>


**Table 3** Incompatibility behaviour of pMG7. R151 determines resistance to carbenicillin, gentamicin, streptomycin, sulphonamides, and tobramycin but not to phages B3, D3, FI16, or G101. Streptomycin was used to select for R151 transfer. Transconjugants were purified and tested for carbenicillin resistance to confirm R151 transfer and for resistance to phages FI16 and G101 as an indication that pMG7 was still present. pMG7 was perfectly stable (20/20 colonies tested) in absence of R151 receipt

<table>
<thead>
<tr>
<th>Donor</th>
<th>Recipient</th>
<th>Frequency of transfer</th>
<th>Transconjugants carrying each plasmid</th>
</tr>
</thead>
<tbody>
<tr>
<td>PU21 (R151)</td>
<td>PA0303</td>
<td>2 x 10^{-8}</td>
<td>3/17 both present</td>
</tr>
<tr>
<td></td>
<td>PA0303 (pMG7)</td>
<td>2 x 10^{-8}</td>
<td></td>
</tr>
</tbody>
</table>
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Table 4  Antibiotic susceptibility (MIC) of mating strain and pMG7 transconjugant

<table>
<thead>
<tr>
<th>Strain</th>
<th>Antibiotic (mg/l)</th>
<th>Ak</th>
<th>Bt</th>
<th>Gm</th>
<th>Km</th>
<th>Nm</th>
<th>Pm</th>
<th>Sis</th>
<th>Tm</th>
</tr>
</thead>
<tbody>
<tr>
<td>PU21 R-</td>
<td></td>
<td>10</td>
<td>50</td>
<td>5</td>
<td>200</td>
<td>100</td>
<td>1000</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>PU21 pMG7</td>
<td></td>
<td>15</td>
<td>50</td>
<td>100</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
</tr>
</tbody>
</table>

Ak = amikacin. Bt = butirosin. Gm = gentamicin. Km = kanamycin. Nm = neomycin. Pm = paromomycin. Sis = sisomicin. Tm = tobramycin.

Table 5  Substrate range of acetyltransferase from PU1 pMG7. Activities expressed relative to kanamycin A, which gave 2560 counts/min in the standard radioactive assay (Haas et al., 1976) with a background of 130 counts/min. Antibiotic abbreviations as in Table 4

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Ak</th>
<th>Bt</th>
<th>GmC1,8</th>
<th>KmA</th>
<th>KmB</th>
<th>KmC</th>
<th>NmB</th>
<th>Pm</th>
<th>Tm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative activity (%)</td>
<td>22</td>
<td>40</td>
<td>52</td>
<td>100</td>
<td>60</td>
<td>92</td>
<td>3</td>
<td>3</td>
<td>51</td>
</tr>
</tbody>
</table>

required to confirm the presence of infection. But again the lack of adequate follow-up made the significance of the initial findings open to conjecture. Antibiotics seemed not to play a major role; only the first and third patients had gentamicin.

Although gentamicin resistance is no longer rare among clinical isolates of Ps. aeruginosa R plasmid-determined resistance to gentamicin or tobramycin appears to be unusual. Nonetheless, outbreaks have occurred in burn units and urological wards in which R plasmid carriage has been demonstrated (Bryan et al., 1974; Jacoby, 1974a; Korfhagen et al., 1975). Bryan et al. (1972) first showed that Ps. aeruginosa rather than E. coli must be used as a recipient strain since plasmids in Pseudomonas may have a limited host range. An example from this outbreak is plasmid pMG7 that could be transmitted by conjugation between Pseudomonas strains but not to E. coli. The transfer frequency for Pseudomonas plasmids is quite variable. Some infect virtually all the cells of a recipient culture whereas others, like those described here, transfer at barely detectable frequency. There are also Pseudomonas plasmids that are non-conjugative or become non-conjugative after transfer (Iyobe et al., 1974; Korfhagen et al., 1976).

Resistant isolates from each of the cases in this outbreak were shown to carry plasmids determining resistance to gentamicin, kanamycin, sisomicin, sulphonamides, tobramycin, and mercuric salts. Each interfered with the propagation of the same subset of bacteriophages and each inhibited the fertility of plasmid RP1. Although transmissible from their strains of origin at comparable frequencies, seven of the eight plasmids were subsequently non-conjugative (Table 2). Possibly they are mobilised by another plasmid coexisting with them in the donor strains. Whether ultraviolet light resistance, which varied among the transconjugants, or the apparent Tra + character of plasmid pMG7 is due to a co-existing plasmid is currently being investigated. The evolution of an initially conjugative hospital R plasmid population to a non-conjugative one has recently been described by Korfhagen et al. (1976). Their R plasmids also originated in Ps. aeruginosa strains causing urinary tract colonisation.

Epidemiological investigation indicated that cross infection with the plasmid-carrying epidemic strain was the major mechanism of spread. However, transmission of an R plasmid apparently occurred from the epidemic strain to other organisms since Ps. aeruginosa isolate No. 1996, differing in serological, phage, and pyocin type from the epidemic strain, also carried a plasmid with properties similar to those found in the epidemic strain (Table 2).

Plasmids of Ps. aeruginosa may be classified by several criteria (Jacoby, 1977). One of the most useful is incompatibility, manifested by the inability of two plasmids belonging to the same incompatibility group to coexist stably in the same host cell (Novick et al., 1976). At least 10 incompatibility groups have been described for Pseudomonas plasmids (Jacoby, 1977). The prototype of incompatibility group P-1 was isolated in the United Kingdom (Datta et al., 1971). Until now plasmids of other incompatibility groups have not been found there in natural isolates. Plasmids from this outbreak belong to incompatibility group P-3. P-3 plasmids have previously been found in resistant Ps. aeruginosa strains in Paris, Chicago, and Athens (Witchitz and
Chabbert, 1971; Bryan, et al., 1974; Kontomichalou et al., 1976). Some are transmissible between Pseudomonas and E. coli, where they belong to incompatibility group C or 6 (Chabbert et al., 1972; Datta and Hedges, 1972). Our results suggest that such plasmids may evolve in Ps. aeruginosa so that transmissibility to E. coli and even to other Pseudomonas strains is lost.

Cell-free extracts of a strain carrying pMG7 contained an active aminoglycoside acetylating enzyme. Activity against kanamycin A but not kanamycin C or paromomycin suggests the presence of a 6'-N-acetylating enzyme (Haas et al., 1976). 6'-N-acetyltransferases with a variety of substrate ranges are known (Jacoby, 1974b; Kawabe et al., 1975a; Kawabe et al., 1975b). Although the transferase determined by pMG7 acylates neomycin B, amikacin, and butirosin (Table 5), strains carrying pMG7 lack enhanced resistance to these aminoglycosides (Table 4). Factors other than antibiotic modification must play an important role in R-plasmid determined aminoglycoside resistance (Dowding and Davies, 1975; Haas et al., 1976).

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