The use of gene probes, immunoassays and tissue culture for the detection of toxin in Vibrio cholerae non-O1

BENGU SAID, SYLVIA M. SCOTLAND and B. ROWE

Laboratory of Enteric Pathogens, Central Public Health Laboratory, 61 Colindale Avenue, London NW9 5HT

Summary. Vibrio cholerae non-O1 strains were screened for the presence of cholera enterotoxin (CT) genes by means of digoxigenin-labelled polynucleotide CT\textsubscript{A} and CT\textsubscript{B} probes. In-vitro production of CT was investigated by the Y1 mouse adrenal cell assay, enzyme-linked immunosorbent assay (ELISA) and a commercial, reversed passive latex agglutination (RPLA) kit. Only two (0.25\%) of 790 strains tested gave positive results with the CT\textsubscript{A} and CT\textsubscript{B} probes. The production of other bacterial cytotoxin(s) made it impossible to use the characteristic cell-rounding effect on Y1 cells for the detection of CT. CT production by the probe-positive strains was confirmed by the immunoassays. Two hundred and fifty-two of the 788 probe-negative strains were tested by both cell assay and immunoassays. Of these, 90\% produced cytotoxin(s) in the cell assay. In addition, 37\% gave positive results in CT-ELISA, but negative results with LT-ELISA and VET-RPLA. These results indicate the presumed presence of a toxin in V. cholerae non-O1 that is able to bind GM\textsubscript{1} and react with antisera to CT, but which is not identical to CT.

Introduction

Vibrio cholerae can be distinguished serologically on the basis of somatic (O) antigens. There are currently 82 known serogroups in addition to V. cholerae O1, the causative agent of epidemic cholera.\textsuperscript{1} V. cholerae non-O1 strains are distributed world-wide, often in brackish surface waters. Some serogroups have been implicated in sporadic cases and outbreaks of gastrointestinal disease. The symptoms vary from bloody diarrhoea with fever to a severe watery diarrhoea indistinguishable from cholera.\textsuperscript{2} Cholera enterotoxin (CT) is a recognised virulence factor of V. cholerae O1 and a heat-labile enterotoxin identical or similar to CT has been found in some isolates of V. cholerae non-O1.\textsuperscript{3,4} CT production in strains of V. cholerae non-O1 has been reported from both Bangladesh and India; Datta-Roy\textsuperscript{5} found 26\% of a small sample of 34 clinical isolates and 10\% of environmental isolates to give positive results in tests for CT production. However, the occurrence rate of CT in V. cholerae non-O1 in other parts of the world is lower. None of 44 human isolates and only 2\% of environmental isolates from Thailand were reported to be CT positive.\textsuperscript{6} Similarly, in a study of 2500 environmental isolates from the Louisiana Gulf coast only 0.3\% produced CT.\textsuperscript{7} However, in none of these studies have the serogroups of V. cholerae non-O1 been reported, nor has a correlation of CT production with serogroup been attempted.

The somatic antigens may be useful indicators of diarrhoeagenic potential within the non-O1 strains. In 1980, the WHO working group\textsuperscript{8} reported a prevalence of serogroups O5 in gastrointestinal disease and O8 in the environment, whereas Donovan\textsuperscript{9} found that serogroups, O2, O5, O7 and O37 predominated in gastrointestinal disease and O4 in the environment. Certain serogroups have also been linked to outbreaks of gastrointestinal illness: e.g., serogroup O5 is thought to have been responsible for a food-borne outbreak in Czechoslovakia in 1965\textsuperscript{10} and serogroup O37 for a water-borne outbreak in the Sudan in 1968.\textsuperscript{11} Recent reports from India and Bangladesh have described large outbreaks due to CT-producing V. cholerae non-O1.\textsuperscript{12,13} The strains from India were untypable (O?) and, although serogrouping for the Bangladesh outbreak remains to be done, both outbreaks may have been caused by strains from the same clone.

The Laboratory of Enteric Pathogens (LEP) has a large collection of V. cholerae non-O1, belonging to many different serogroups, isolated from over 50 countries. To assess the correlation of CT with serogroup, strains from both environmental and human sources were examined for the presence of the CT genes and for the production of heat-labile enterotoxins with the Y1 cell test and immunoassays.

Materials and methods

Bacterial strains

Seven hundred and eight wild-type strains of
*V.* *cholerae* non-O1, from both human and environmental sources, were studied; all strains were taken from the culture collection of LEP. Of these, 310 strains belonged to 49 serogroups, 334 strains were untypable (O?) and 64 strains were rough (OR). The type strains of *V. cholerae* non-O1 (serogroups O2–O83) were kindly provided by Dr R. Sakazaki. The *V. cholerae* non-O1 control strain WBDV-101E (serovar O49, CT) was kindly provided by Dr P. Echeverria. The *V. cholerae* O1 control strain (ES5116, CT) came from the LEP culture collection. All *V. cholerae* strains were maintained on nutrient agar slopes at room temperature. The control enterotoxin, (LT+ STa+)14 was maintained on a Dorset's egg slope at room temperature. The control *Escherichia coli* strain B7A (O148:H28), which produces both heat-labile enterotoxin and heat-stable enterotoxin, (LT+ STa+)14 was maintained on a Dorset's egg slope at room temperature.

**Preparation and digoxigenin-labelling of polynucleotide CTα and CTβ probes**

Strains of *E. coli* K12 carrying plasmids with cloned CT gene sequences were prepared to large quantities of covalently closed circular DNA.16 The CT gene sequence from *V. cholerae* El Tor 6274616 cloned into plasmid pBR325 (pCVD27) was provided by Dr J. B. Kaper. A 554-bp CTα probe was cut from pCVD27 after digestion with EcoRI (Life Technologies Ltd, Uxbridge, Middlesex). The recombinant plasmid pCT19 is known to contain CTα, and part of CTβ;17 the gene sequences were cloned and subcloned from *V. cholerae* 1621 into pACYC184 as described by Gennero et al.18 A 550-bp CTα probe was cut from plasmid pCT19 after digestion with XbaI and HincII. Probe fragments were separated on and excised from agarose gels and purified with the Geneclean Bio 101 kit (Stratech Scientific Ltd, Luton, Bedfordshire). The cloned polynucleotide probes were labelled with digoxigenin according to the manufacturer's instructions (Boehringer Corporation Ltd, Lewes, East Sussex). Unincorporated nucleotides were removed with QIAGEN-tip 5 (Diagen, Dusseldorf, Germany) according to the manufacturer's instructions and the labelled probe was stored at -20°C.

**Preparation of cultures for DNA hybridisation**

Bacterial cultures, grown at 37°C with aeration for 18 h, were spotted on to Hybond N nylon membranes (Amersham International, Aylesbury, Buckinghamshire) placed on nutrient agar plates. Colonies were grown at 37°C for 6 h and the cells were lysed and DNA denatured as described by Maniatis et al.15

**Hybridisation with polynucleotide probes**

Hybridisations were performed in heat-sealed plastic bags which were placed in a water bath at the appropriate temperature with shaking. Hybridisation was carried out at 68°C (high stringency conditions identifying sequences with > 80% identity) on colony blot membranes. In some experiments, lower stringency conditions (37°C) were used, allowing the hybridisation of sequences with only 60% identity.

Colony blot membranes were pre-washed with 10 ml of a hybridisation solution per 50 cm² membrane for 1 h at 68°C. The hybridisation fluid contains; five times concentrated SSC (where SSC consists of NaCl 0.88 %, trisodium citrate 0.44 %), blocking reagent (Boehringer) 0.5 %, N-lauroylsarcosine 0.1 %, SDS 0.02 %.) The membranes were washed and pre-hybridised with fresh solution for 2 h. Hybridisation was allowed to proceed for 18 h, with hybridisation solution 1.25 ml/50 cm² membrane, containing freshly denatured probe 26 ng/ml and freshly denatured herring sperm DNA 100 µg/ml. Membranes were washed with double strength SSC, SDS 0.1 % for 5 min at room temperature followed by two washes of 15 min each of, tenth dilution SSC, SDS 0.1 % at 68°C. Detection procedures were as described by Boehringer.

The protocol for hybridisation at 37°C did not differ from that described above but, as the hybridisation solution was formamide 25%, five times concentrated SSC, Ficoll 0.01%, polyvinylpyrrolidone 0.01%, bovine serum albumin 0.01%, SDS 0.1%, and 1 mM EDTA. The post-hybridisation washes were with five times concentrated SSC, SDS 0.1% at 54.5°C for 1 h, followed by double strength SSC at room temperature for 30 s.

**Bacterial culture and preparation of crude toxin**

For routine testing of CT production by *V. cholerae* O1, bacteria were grown overnight in Syncase sucrose broth19 at 37°C with agitation. Initially these conditions were used to test *V. cholerae* non-O1 strains. For further assays of CT production, culture filtrates were prepared by growing the organisms in various media: Syncase sucrose broth, Syncase glucose broth,19 Trypticase Soy Broth (Becton Dickinson, Cockeysville, USA),20 Brain Heart Infusion Broth (Unipath Ltd, Basingstoke, Hampshire),21 and casaminio yeast extract broth.22,23 Strains were inoculated into 10-ml volumes of the respective broths and incubated statically in a 250-ml flask at 30°C and 37°C, or with agitation (120 oscillations/min). The overnight culture was then centrifuged (17000 g for 30 min at 4°C) and the supernate was sterilised by filtration through a Millipore filter (pore size 0.2 µm). A sample of the culture supernate was also heated at 100°C for 15 min. The filtrate and the heated sample were used for both tissue culture tests and immunoassays. All tests were done in duplicate.

**Y1 adrenal cell assay for toxin**

Culture filtrates were tested for CT on monolayers of Y1 cells.51,52 CT and *E. coli* LT characteristically lead to a rounding of the Y1 cells. The effect of the
heated preparation was compared with that of the unheated to ensure that rounding was due to a heat-labile factor. Doubling dilutions of filtrate were used to determine titres of heat-labile enterotoxin and cytotoxin. Neutralisation with antiserum against CT or LT was performed to confirm the specificity of the rounding effect. For the neutralisations, 25-µl volumes of filtrate and antiserum (1 in 200) were incubated together in 200 µl of growth medium for 3 h at 37°C before being transferred on to Y1 cells.

Enzyme-linked immunosorbent assay

A modification of the GM1-ELISA methods of Svennerholm and Holmgren22 and Sack26 was used. A solution of ganglioside GM1 (2 µg/ml Supelco, Bellefonte, USA) 100 µl in PBS was added to micro-ELISA plates (Dyneatech Laboratories Ltd, Billingshurst, Sussex) and incubated overnight at room temperature. Extra binding sites were blocked by adding 200 µl of BSA (Sigma, Poole, Dorset) 1% w/v dissolved in PBS, for 30 min at 37°C. The steps of the procedure were as follows. After each step the plates were washed three times with PBS containing Tween 20 (PBST) 0.05% v/v; 100 µl of the filtrate were added and the plates were incubated at room temperature for 2 h. One hundred µl of the appropriate antiserum, diluted 1 in 200 in PBS were added: for CT-ELISA, rabbit anti-CT antiserum (LEP); for CTn-ELISA, goat anti-CTn antiserum (Calbiochem Novabiochem, Nottingham); for LT-ELISA, rabbit anti-LT antiserum (LEP). The plates were then incubated for 18 h at room temperature. Alkaline phosphatase-conjugated goat anti-rabbit immunoglobulin (Sigma) 100 µl or alkaline phosphatase-conjugated rabbit anti-goat immunoglobulin (Sigma) 100 µl were added. Antibody preparations were diluted 1 in 7000 and 1 in 3000 in PBS respectively. The plates were incubated at room temperature for 2 h. Then 200 µl of p-nitrophenyl phosphate (1 mg/ml in diethanolamine buffer) were added. After 100 min in the dark at room temperature, the reaction was stopped with 25 µl of 1 M NaOH and the absorbance was read at 405 nm. A control (strain E51116) was included on each plate.

Reversed passive latex agglutination

The VET-RPLA kit (Unipath Ltd) was used for the detection of CT and LT. Doubling dilutions of filtered supernates were tested according to the manufacturer’s protocol.

Results

CTn and CTb probes at low stringency

The heat-labile enterotoxin produced by E. coli is known to be related to CT.27 However, in this study, hybridisation experiments showed that LT+ E. coli hybridised with the CT probes only at low stringency. V. cholerae non-01 strains were also tested for hybridisation at low stringency with the CTn, and CTb probes to determine if a CT/LT-related toxin was being produced. A total of 252 strains (representing 37 different serogroups from both human and environmental sources) was tested and all were probe-negative under low stringency conditions.

Y1 mouse adrenal cell assay

In all, 226 (89.6%) of 252 V. cholerae non-01 strains tested in the Y1 cell assay produced a cytotoxic effect on Y1 cells within 24 h; the remaining 26 strains were completely negative. Of the identifiable serogroups producing cytotoxin, the most common were: O26 (23 of 26 strains tested were cytotoxic positive), O2 (10 of 10), O19 (9 of 9), O5 (7 of 7), O13 (4 of 4), O14 (4 of 4), O49 (4 of 4), O76 (4 of 4) and O37 (3 of 3). It is noteworthy that all strains from serogroups O2, O5, O13 and O37 produced cytotoxin, because these serogroups have been reported to be associated with human disease.8,9 The probe-positive V. cholerae non-01 strains also produced cytotxin(s) which made it impossible to distinguish true rounding from early cytotoxic effects. Even when filtrates were diluted to 1 in 156250, cytotoxin was still present. The cytotoxic effect present in the filtrates, even as CT, was destroyed by heating at 100°C for 15 min, but the effect was not neutralised by antiserum to cholera toxin. The control V. cholerae O1 strain did not produce cytotxin under these conditions, but did cause typical rounding of the cells which was confirmed as CT by neutralisation. Similarly, E. coli strain B7A produced rounding typical of LT and this effect could be neutralised with anti-cholera antiserum.

The probe-positive V. cholerae strains and E. coli strain B7A were tested for CT (or LT) production
under various growth conditions (table). For the non-
O1 strains, none of the conditions allowed the dif-
ferentiation of CT from the cytotoxin in the Y1 test. For
strain E51116, the highest CT titre (2560) was
obtained after overnight incubation with agitation at
37°C with Syncase sucrose broth.

**Discussion**

In this study, *V. cholerae* non-O1 strains from 50
countries, isolated from both environmental and
human sources, were tested for the production of CT
by four methods.

Of the *V. cholerae* non-O1 strains which were tested
with the CT probes, only three gave positive results,
one belonging to serogroup O49 (this was the control
strain WBDV-101E), one to O37 and one O7 strain
(from Egypt). There was no apparent correlation of
serogroup with CT production. The low occurrence of
CT probe-positive *V. cholerae* non-O1 strains (0.25%
) is in agreement with previous reports.6,7

CT and LT are part of a heterogeneous family of
enterotoxins and different forms of LT have been
described; i.e., LTh-I, LTp-I, LTIIa and LTIIb.28 The
suggestion has been made that there may be differences
in molecular structure between enterotoxins produced
by different serovars of *V. cholerae*.39 In the present
study, hybridisation at low stringency with CT<sub>H</sub>
and CT<sub>p</sub> probes provided no evidence for genes in
*V. cholerae* non-O1 encoding heat-labile enterotoxins
related to CT or LT. As CT<sub>H</sub> is the more conserved
part of the toxin in the CT/LT family of toxins39 it was

<table>
<thead>
<tr>
<th>Culture medium</th>
<th>Aeration/ temperature (°C)</th>
<th>ELISA* and VET-RPLA*</th>
<th>Y1 Cell Test†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syncase</td>
<td>+/37</td>
<td>E55879 O7 1322-69 O37 WBDV-101E O49 E51116 O1 B7A E. coli</td>
<td>E55879 O7 1322-69 O37 WBDV-101E O49 E51116 O1 B7A E. coli</td>
</tr>
<tr>
<td>sucrone</td>
<td>+/37</td>
<td>c c c c 2560 156250</td>
<td></td>
</tr>
<tr>
<td>broth</td>
<td>+/37</td>
<td>c c c 40 6250</td>
<td></td>
</tr>
<tr>
<td>glucose</td>
<td>+/37</td>
<td>c c 1280 250</td>
<td></td>
</tr>
<tr>
<td>broth</td>
<td>+/37</td>
<td>c c c 40 6250</td>
<td></td>
</tr>
<tr>
<td>Trypticase</td>
<td>+/37</td>
<td>c c c 156250</td>
<td></td>
</tr>
<tr>
<td>soy broth</td>
<td>+/37</td>
<td>c c c 320 250</td>
<td></td>
</tr>
<tr>
<td>Brain heart</td>
<td>+/37</td>
<td>c c c 40 250</td>
<td></td>
</tr>
<tr>
<td>infusion broth</td>
<td>+/37</td>
<td>c c c 20 6250</td>
<td></td>
</tr>
<tr>
<td>Casamino</td>
<td>+/37</td>
<td>c c c 40 250</td>
<td></td>
</tr>
<tr>
<td>yeast</td>
<td>+/37</td>
<td>c c c 40 250</td>
<td></td>
</tr>
<tr>
<td>extract broth</td>
<td>+/37</td>
<td>c c c 40 250</td>
<td></td>
</tr>
<tr>
<td>ND, not done; c, cytotoxin.</td>
<td></td>
<td>Figure in parenthesis is titre of reversed passive latex agglutination for CT and LT.</td>
<td>The final titre is shown for cytotoxic response.</td>
</tr>
</tbody>
</table>
considered possible that some strains might hybridise with the CT probe only. However, no such strain was detected in this study.

All probe-positive strains were confirmed as CT-producers by immunoassays. However, the CT-ELISA and CT2-ELISA also gave positive results with some strains which were negative with the CT probes. The ELISA assay depends on the abilities of the GM, ganglioside to bind heat-labile enterotoxins, with bound toxin detected by specific antitoxin antibodies. The strains that gave positive CT-ELISA results may be producing a heat-labile enterotoxin distinct from CT, but nevertheless able to bind to ganglioside GM. This presumed toxin also appeared to share epitopes with CT, and more specifically with CT.

Because of the production of cytotoxin, which masks cytotoxic effects on Y1 cells, it was not possible to show neutralisation of the putative toxin.

All CT-ELISA-positive strains produced cytotoxin in the Y1 cell assay. However, the CT-ELISA did not detect the cytotoxin, since most strains that gave negative results in the CT-ELISA produced cytotoxin on Y1 cells. Cytotoxin production may be important for virulence, as representatives of all the serogroups associated with diarrhoeal illness (O2, O5, O13 and O37) were found to produce cytotoxin.

The production of CT by V. cholerae O1 and LT by E. coli strain B7A was detected readily by the conventional Y1 cell assay and immunoassays. The probe-positive V. cholerae non-O1 strains produced cytotoxin which effectively masked the CT rounding in the Y1 cell assay and varying the growth conditions did not affect the result. The immunoassays used could detect the presence of CT even in the presence of cytotoxin. The optimal condition for CT production, as detected by immunoassays, was growth in Syncase sucrose broth at 37°C with agitation.

Recent volunteer studies showed that some V. cholerae non-O1 strains, which did not produce CT, caused diarrhoea of a similar severity to that seen in cholera. This suggests that factors other than CT, such as the presumed toxin identified in this study, may be important in the pathogenesis of diarrhoea caused by V. cholerae non-O1 strains.

In the present study, < 1% of V. cholerae non-O1 strains produced CT immunologically indistinguishable from the CT produced by serogroup O1. Because these few strains also produced cytotoxins, CT could be detected only by probe, or by immunoassay under specific growth conditions. Of the probe-negative strains, most (90%) produced cytotoxin(s) detected by Y1 cells. In addition, 37% of probe-negative strains gave positive results in the ELISA for CT but negative results in the ELISA for E. coli LT and VET-RPLA. The substance produced was distinct from the cytotoxin(s) detected in the Y1 cell assay. This substance could be detected only in the CT-ELISAs and may be a toxin structurally and antigenically similar to CT. The role in diarrhoeal disease of both the cytotoxin and the substance detected by the CT-ELISA needs to be evaluated.

The help of Dr G. A. Willshaw and Ms A. Thomas with the probe work, and of Mr T. Cheasty and Mr N. Stokes with the serotyping was greatly appreciated.

References

21. Nishibuchi M, Seidler RJ. Medium-dependent production of


