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(57) **Abrégé/Abstract:**

Disclosed is a newly identified and characterized type III secretion system in *Aeromonas salmonicida*. The invention also encompasses the use of components of the novel secretion system in immunoprotection against *A.salmonicida* infection, as well as other diagnostic and therapeutic uses thereof.

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(54) Title: TYPE III SECRETION PATHWAY IN AEROMONAS SALMONICIDA, AND USES THEREFOR

(57) Abstract: Disclosed is a newly identified and characterized type III secretion system in *Aeromonas salmonicida*. The invention also encompasses the use of components of the novel secretion system in immunoprotection against *A. salmonicida* infection, as well as other diagnostic and therapeutic uses thereof.



**WO 02/040514 A3**

**NOVEL TYPE III SECRETION PATHWAY IN *AEROMONAS SALMONICIDA*,  
AND USES THEREFOR**

**FIELD OF THE INVENTION**

This invention relates to bacterial secretion systems, and in particular to a newly identified and characterized type III secretion system in *Aeromonas salmonicida*. The invention also encompasses the use of components of the novel secretion system in immunoprotection against *A. salmonicida* infection, as well as other diagnostic and therapeutic uses thereof.

**BACKGROUND OF THE INVENTION**

Various publications are referenced throughout this publication, and full citations for each of these publications are provided at the end of the Detailed Description.

*Aeromonas salmonicida*, a Gram-negative, facultatively anaerobic, non-motile, rod shaped bacterium, growing at temperatures around 20°C, is the etiological agent of furunculosis in salmonids, causing most severe economic losses in production farms of salmon and trout. The disease is characterised in the sub-acute or chronic form by the presence of haemorrhagic necrotic lesions in the gills, gut and muscle, while in the acute form fish die apparently from toxæmia without showing particular external signs.

Due to the high contagiousity of the disease and the high mortality in salmon of all ages, particularly in the sea water growers, large amounts of antibiotics are used in closed and open waters for therapy of furunculosis (Munro and Hastings, 1993). Vaccination has become an important strategy to control furunculosis in fish farms (Ellis, 1997). However, the currently applied whole cell antigen vaccines seem to show considerable variability in efficacy, the origin of which remains currently unexplained (Thornton et al., 1993).

Knowledge of the mechanisms of pathogenicity of *A. salmonicida*, and in particular of the main virulence factors involved, is essential in the development of efficient strategies to prevent outbreaks of furunculosis caused by *A. salmonicida*. Currently, several potential virulence factors of *A. salmonicida* have been reported, including a surface-layer protein (Chu et al., 1991), the hemolysins ASH1, ASH3, ASH4 (Hirono and Aoki, 1993), salmolysin (Titball

and Munn, 1985), the serine protease AspA (Whitby et al., 1992) and the glycerolipid-cholesterol acyltransferase (GCAT) (Lee and Ellis, 1990), but their role in pathogenesis is unclear and many of them seem not to play a primary role in virulence. This was demonstrated by *A. salmonicida* strains with deletion mutants of the GCAT and *aspA* genes which had no influence on virulence of the strains in inducing furunculosis.

## SUMMARY OF THE INVENTION

A new ADP-ribosylating toxin named AexT (*Aeromonas* exoenzyme T) encoded by the gene *aexT* was identified in a virulent strain of *A. salmonicida*. *A. salmonicida* strains that were propagated for several passages on culture medium had lost expression of AexT, but still retained the *aexT* gene. AexT shows amino acid sequence similarity to the ADP-ribosyltransferase toxins ExoS and ExoT of *Pseudomonas aeruginosa* which are secreted by a type III-dependent secretion mechanism (Yahr et al., 1996). Regulation of *aexT* was shown to be dependent on contact with fish cells and could also be induced by Ca<sup>2+</sup> depletion of the medium. The *aexT* gene was found to be preceded by a consensus sequence for binding of a transcriptional activator known in *P. aeruginosa* as ExsA which is involved in type III mediated gene expression (Frank, 1997).

Based on these observations, we used broad range gene probes to identify in *A. salmonicida* a novel type III secretion system by means of the gene *acrD* (*Aeromonas calcium response D*) encoding a transmembrane spanning protein. The *acrD* gene has a high similarity to *lcrD*, a protein of the *Yersinia* sp. which is an inner membrane protein of the type III secretion apparatus in *Yersinia* sp. The *acrD* gene is flanked by further typical type III secretion genes which were designated *acr1*, *acr2*, *acr3*, *acr4*, *acrD*, *acrR*, *acrG*, *acrV*, and *acrH*, and which show significant similarity to *pcr1*, *pcr2*, *pcr3*, *pcr4*, *pcrD*, *pcrR*, *pcrG*, *pcrV*, and *pcrH* of *Pseudomonas aeruginosa* and to *tyeA*, *sycN*, *yscX*, *yscY*, *lcrD*, *lcrR*, *lcrG*, *lcrV*, and *lcrH* of *Yersinia enterocolitica*. All these genes play a predominant role in building up the type III secretion apparatus in the respective bacterium, including the regulation of the low calcium response (LCR) and chaperon functions. The genes isolated from *A. salmonicida* belong to the analogue of the *virA* operon, which is central in the type III secretion pathway of many Gram-negative pathogens of human, animals and plants (Fenselau et al., 1992; Gough et al., 1992; Michiels and Cornelis, 1991).

We have also determined that the type III secretion system in *A. salmonicida* is located on a 84 kb plasmid which is rapidly lost upon growth in culture medium. Biosynthesis of AcrV in *A. salmonicida*, the analogue to LcrV in *Yersinia*, requires as a trigger either low Ca<sup>2+</sup> conditions or contact with fish cells. Upon infection with *A. salmonicida* expressing AcrV, the cultured cells undergo significant morphological changes. Cultures derived from originally

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virulent *A. salmonicida* strains, which had lost the type III secretion genes including AcrV, lost virulence as they did not affect rainbow trout gonad cells morphologically after infection. Concomitantly to loss of the type III secretion genes, these cultures lost the expression of the *aexT* gene which specifies the ADP-ribosylating toxin of *A. salmonicida*.

Rainbow trout gonad cells infected with the virulent *A. salmonicida* and incubated in antiserum directed against recombinant AcrV-His protein could be protected from the toxic effect and showed only weak morphological changes. AcrV, which belongs to the type III secretion proteins is a determinative factor involved in virulence mechanisms of *A. salmonicida*, and is expected to provide new insights into basic mechanisms of pathogenicity of bacterial species. The components of the type III secretion system of *A. salmonicida* may be used as antigens for the development of sub-unit vaccines against infection of fish by *A. salmonicida*.

In one embodiment, the invention comprises an isolated 5.7 kb nucleic acid segment (SEQ ID NO:10) containing the type III secretion genes of *A. salmonicida*. In another embodiment, the invention comprises a nucleic acid segment that encodes protein having the amino acid sequence of SEQ ID NOS:1, 2, 3, 4, 5, 6, 7, 8, and 9, including variants that retain either biological activity or immunogenicity or both. Due to the degeneracy of the genetic code and the possible presence of flanking nucleic acid fragments outside of the coding regions, it will be understood that many different nucleic acid sequences may encode the amino acid sequence of SEQ ID NO NOS:1, 2, 3, 4, 5, 6, 7, 8, or 9, and variants, and that all such sequences would be encompassed within the scope of the present invention.

In a further embodiment, the invention relates to the use of AcrV as an immunogen, and to the use of AcrV in a recombinant or traditional vaccine to reduce the incidence of infection by *A. salmonicida*.

In another embodiment, the invention provides a means of diagnosing *A. salmonicida*, or other bacteria found to contain AcrV homologues, by the detection of the AcrV protein or the homologous proteins.

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In one aspect, the invention relates to an isolated protein selected from SEQ ID NO:1; SEQ ID NO:2; SEQ ID NO:3; SEQ ID NO:4; SEQ ID NO:5; SEQ ID NO:6; SEQ ID NO:7; SEQ ID NO:8; or SEQ ID NO:9.

5 In another aspect, the invention relates to an isolated nucleic acid fragment encoding a protein comprising an amino acid sequence selected from SEQ ID NO:1; SEQ ID NO:2; SEQ ID NO:3; SEQ ID NO:4; SEQ ID NO:5; SEQ ID NO:6; SEQ ID NO:7; SEQ ID NO:8; or SEQ ID NO:9, or a protein comprising an amino acid sequence that is at least 85% identical to any one of SEQ ID NO:1-9 and encompassing amino acid substitutions, additions and deletions that do not alter the immunogenicity of said protein.

10 In another aspect, the invention relates to an isolated nucleic acid fragment comprising SEQ ID NO:10, or the complement thereof.

In another aspect, the invention relates to an immunogenic, immunological or vaccine composition comprising the protein or polypeptide as described above, and a pharmaceutically acceptable carrier.

15 In another aspect, the invention relates to an expression vector comprising a nucleic acid molecule encoding a polypeptide selected from SEQ ID NO:1; SEQ ID NO:2; SEQ ID NO:3; SEQ ID NO:4; SEQ ID NO:5; SEQ ID NO:6; SEQ ID NO:7; SEQ ID NO:8; or SEQ ID NO:9.

20 In another aspect, the invention relates to use of *Aeromonas* calcium response V (AcrV) comprising the amino acid sequence of SEQ ID NO:8 or the DNA encoding the amino acid sequence of SEQ ID NO:8 in the manufacture of a diagnostic agent.

In another aspect, the invention relates to an antiserum that specifically binds to a recombinant *Aeromonas* calcium response V (AcrV) comprising the amino acid sequence of SEQ ID NO:8, for use in protecting fish from the toxic effect of a virulent strain of  
25 *Aeromonas salmonicida*.

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## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a genetic map of the type III secretion genes found in *A. salmonicida*. Boxes with arrowheads indicate open reading frames (ORFs). The size of the different genes (in kilobases) is shown by the scale bar. A restriction map containing restriction enzymes *SacI*,  
5 *PstI*, *NotI*, *BamHI*, and *SalI* is shown. Abbreviation used: acr, Aeromonas calcium response.

FIG. 2 is a segregation curve of *A. salmonicida* JF2267. An *A. salmonicida* JF2267 LB-culture was first incubated 2 ½ hrs at 19°C and then at 22°C for 7 hrs. Colony-blotting was performed to analyze the LB-culture at 10 different time points for positive, respectively negative colonies.

FIG. 3 shows a pulsed-field gel electrophoresis of *A. salmonicida* strain JF2267, and strain JF2397. (Lane 1) JF2267, undigested. (Lane 2) JF2397, undigested. (Lane 3) JF2267 digested with *NotI*. (Lane 4) JF2397 digested with *NotI*. (Lane 5) Low Range PFG Marker (New England Biolabs). The white arrows indicate the bands that hybridized on Southern blots with the *acrD* gene probe.

FIG. 4 shows infection of fish cells with *A. salmonicida* ATCC 33658<sup>T</sup>, JF2267, and JF2397. RTG-2 cells infected with JF2267 (A), ATCC 33658<sup>T</sup> (B), JF2397 (C), and pure PBS (D). RTG-2 cells infected with JF2267 and monospecific polyclonal antibodies against AcrV were protected (E), whereas RTG-2 cells infected with JF2267 and anti-AcrV preserum were not. Pictures were taken 24 hrs after infection, respectively 21 hrs after the protection assay under a phase contrast microscope.

FIG. 5 shows low Ca<sup>2+</sup> response induced AcrV expression in *A. salmonicida* JF2267. The picture shows an immunoblot reacted with specific rabbit anti-AcrV antiserum. Strains ATCC 33658<sup>T</sup> (lane 2), JF2267 (lane 3) and JF2397 (lane 4) were grown in Ca<sup>2+</sup> depleted medium, harvested by centrifugation and analyzed on 15% SDS PAGE followed by immunoblotting. Lane 1 contains purified recombinant AcrV-His protein as a control.

#### DETAILED DESCRIPTION

A 5.7 kb segment containing type III secretion genes of *A. salmonicida* that were cloned and sequenced correspond to the *pcr* locus (*Pseudomonas calcium response*) of *Pseudomonas aeruginosa* (Frank, 1997; Yahr et al., 1997b) and the *virA* operon and genes of the following operon of *Yersinia enterocolitica* (Cheng and Schneewind, 2000; Iriarte and Cornelis, 1999; Plano et al., 1991; Skrzypek and Straley, 1993; Motin et al., 1994; Price and Straley, 1989) and other Gram-negative animal and plant pathogens (Fenselau et al., 1992; Gough et al., 1992; Michiels and Cornelis, 1991). The most conserved gene at this locus was revealed to be the *acrD* gene encoding the AcrD protein, which showed 82% identical aa to the transmembrane spanning core proteins LcrD of the injectisome of the *Y. enterocolitica* type III secretion apparatus and PcrD of the injectisome of the *P. aeruginosa* type III secretion apparatus (Yahr et al., 1997b; Plano et al., 1991). Due to this high similarity, we conclude AcrD to have the analogous functions in the injectisome of the *A. salmonicida* type III secretion pathway.

The least conserved protein encoded on the cloned and analyzed segment is AcrV, which shows only 35% identical aa to PcrV of *P. aeruginosa* and 37% identity to LcrV of *Y. enterocolitica*. The main role of LcrV and PcrV, and accordingly also of AcrV, is assumed to be involved in sensing the bacterium-host interactions (Sawa et al., 1999; Bergman et al., 1991). We therefore interpret the significantly higher dissimilarity between AcrV and LcrV or PcrV, compared to the other gene products of the type III secretion locus (Table 2), to be due to the host specificity which seems to be determined by AcrV, LcrV or PcrV.

Our analyses revealed the *A. salmonicida* type III secretion genes to be located on a plasmid of 84 kb. The plasmid was shown to be lost very easily in standard growth media, in particular after a slight raise in growth temperature. Concomitant to the loss of the type III genes in *A. salmonicida*, we detected the loss in virulence of the strain as measured by the infection of RTG-2 fish cell cultures, as well as the loss of production of ADP-ribosylating toxin *aexT* in supernatants and bacterial cell pellets of low  $Ca^{2+}$  response induced *A. salmonicida* cultures. It is also noted that AexT biosynthesis induced by contact of *A. salmonicida* with RTG-2 fish cells disappeared in those strains or subcultures that had lost the type III secretion genes. Expression of the *aexT* gene must therefore be regulated by a mechanism which is dependent on type III secretion genes. In this context it must be noted that several genes of the type III secretion pathway of *Yersinia* spp., in particular LcrV, are down regulated and secretion and production of effector proteins is completely blocked in the presence of millimolar amounts of  $Ca^{2+}$  (Forsberg et al., 1987). It also became apparent from tissue culture infection models that the absence of  $Ca^{2+}$  in vitro mimics a yet undefined signal that is received by *Yersinia* species when they are adherent to eukaryotic cells and that induce both type III secretion genes and effector molecules such as YopE and Yops (Cornelis, 1998).

The dependence of *aexT* expression on type III secretion mechanism was also indicated by the presence of a consensus sequence upstream the *aexT* toxin gene in *A. salmonicida*, which shows full homology to the binding site of a transcriptional activator, known in *P. aeruginosa* as ExsA, which is involved in type III dependent gene expression (Frank, 1997). The expression of *aexT* in *A. salmonicida* is thus dependent on a functional type III secretion mechanism. The lack of production of AexT as detected in the type strain of *A. salmonicida* ATCC 33658<sup>T</sup> as well as in the strain JF2397 which was derived from an originally virulent *A. salmonicida* strain, JF2267, in spite of the presence of a functional *aexT* gene, must therefore be due to the loss of the type III secretion pathway.

The AcrV protein of the novel type III secretion pathway of *A. salmonicida* plays an important role in pathogenesis by its role as a sensor and regulator of the system, as shown in other type III secretion systems. An important role in the secretion-related regulatory role in the

low  $\text{Ca}^{2+}$  response of *Y. pestis* is attributed to LcrV, which is localized to the bacterial surface and required for targeting of Yops of *Y. pestis* (Fields and Straley, 1999; Nilles et al., 1997). In addition, it was postulated that LcrV is also secreted by a special pathway which results its localization in the cytosol of infected cells but not the surrounding medium (Fields and Straley, 1999). Using a tissue cell model, it was shown that antiserum directed against LcrV prevented *Y. pestis* from injecting the Yop effector molecules into the host cells (Pettersson et al., 1999; Hueck, 1998). Active immunization of mice with recombinant LcrV antigen efficiently protected mice against challenge with *Y. pestis* (Leary et al., 1995). Our results showed that antibodies directed against recombinant AcrV, the analogous protein to LcrV, protected fish RTG-2 cells from damage caused by virulent *A. salmonicida* strain JF2267 and demonstrated that the AcrV plays an important role in type III secretion pathway mediated virulence of *A. salmonicida*.

The newly found type III secretion pathway plays a central role in pathogenicity of *A. salmonicida* via the secretion and direct injection of the ADP-ribosylating toxin AexT into the target cells. Loss of the type III secretion pathway, which is frequently observed, is due to the instability of a kb plasmid under culture conditions. Furthermore, loss of type III secretion genes such as *acrD* and *acrV* abolished expression of the *aexT* gene, and led to loss of virulence of *A. salmonicida*. As shown, surface exposed gene products of this type III secretion pathway, in particular AcrV, are potent candidates for new vaccines for the immune prophylaxis of fish against furunculosis.

The invention is further described by way of the following examples and results, which are not to be considered as limiting the scope of the invention. It will be appreciated by those skilled in the art, in light of this disclosure, that many changes can be made in the specific embodiments disclosed without departing from the scope of the invention.

## EXAMPLES AND RESULTS

### Materials and Methods

Bacterial strains, growth conditions and cloning vectors:

*A. salmonicida* strains are listed in Table 1. *A. salmonicida* type strain ATCC 33658<sup>T</sup> was purchased from the American Type Culture Collection. *A. salmonicida* strain JF2267 was freshly isolated from an arctic char (*Savelinus alpinus*) showing typical symptoms of furunculosis. *A. salmonicida* strain JF2397 was derived from strain JF2267 by repeated single colony isolations after each of nine passages propagated on LB agar medium at 22°C for two days each passage.

*A. salmonicida* strains were routinely cultured on blood agar plates (Trypticase soy agar supplemented with 0.1% CaCl<sub>2</sub> and 5% sheep blood) at 19°C unless otherwise mentioned.

Liquid cultures of *A. salmonicida* were made by inoculation of Trypticase soy broth (TSB) (2.75 g/100 ml Trypticase soy broth without Dextrose (BBL® 11774, Becton Dickinson AG, Basle, Switzerland), 0.1% Glycerol, 0.1 M L-Glutamic acid pH 7.3) with fresh culture from solid medium and subsequent growth for 18 h at 19°C. For growth in Ca<sup>2+</sup>-restricted medium, TSB was supplemented with 10 mM Nitrilotriacetic acid (Titriplex I, Merck 1.08416, Darmstadt, Germany).

For cloning and expression of cloned genes, *Escherichia coli* strains XL1-blue (*recA1 endA1 gyrA96 thi-1 hsdR17 supE44 relA1 lac* [F' *proAB lacI<sup>q</sup>ZΔM15 Tn10* (Tet<sup>r</sup>)] (Bullock et al., 1987), and BL21(DE3) (F' *dcm ompT hsdS(r<sub>B</sub>- m<sub>B</sub>-)* gal λ(DE3)) (Studier et al., 1990) respectively, were used. Plasmid pBluescriptII-SK<sup>-</sup> (Stratagene, La Jolla, CA, USA) was used as basic cloning vector. For the construction of genes encoding poly-Histidine fusion proteins and their expression, plasmid pETHIS-1, a T7 promoter based expression vector (Schaller et al., 1999) was used. *E. coli* strains were grown at 37°C in Luria-Bertani broth (LB) supplemented when necessary with ampicillin (50 μg/ml) for selection and maintenance of recombinant plasmids. When blue-white selection with pBluescriptII-SK<sup>-</sup> was performed, 125 μM X-Gal medium was supplemented with 5-bromo-4-chloro-3-indolyl-β-D-thiogalacto-pyranoside.

Preparation of genomic DNA, cloning and sequencing procedures:

Genomic DNA of *A. salmonicida* was extracted by the guanidium hydrochloride method (Pitcher et al., 1989). A partial gene library of *A. salmonicida* JF2267 was constructed by cloning agarose gel purified *SacI-SalI* digested fragments of 4 to 6 kb size into vector pBluescriptII-SK<sup>-</sup> using standard procedures (Ausubel et al., 1999). Recombinant plasmids were screened by colony blot (Ausubel et al., 1999) using digoxigenin (DIG)-labeled DNA probes as described previously (Braun et al., 1999). Plasmids from *A. salmonicida* were purified using the method of Birnboim and Doly (Birnboim and Doly, 1979).

To construct a genomic library from *A. salmonicida* JF2267, 0.1 μg of DNA partially digested with *Sau3a* was ligated to ZapExpress *Bam*HI prepared arms (Pharmacia, Uppsala, Sweden) and packed into phage Lambda. Two-hundred μl of freshly grown XL1-blue MRF' cells (Pharmacia) resuspended in 10 mM MgSO<sub>4</sub> were infected with the packed phages during 15 min at 37°C. Three ml of preheated (50°C) Top Agarose (LB-broth containing 0.7% Agarose) supplemented with IPTG and X-Gal for blue/white selection were added and the mixture was poured onto an LB-Agar plate. Plates were incubated overnight at 37°C and then used for

screening of plaques. Positive plaques were cut out and stored overnight at 4°C in 0.5 ml SM-buffer (100 mM NaCl, 8 mM MgSO<sub>4</sub>, 50 mM Tris, pH 7.5, and 0.01% gelatine) containing 20 µl chloroform. 20 ml overnight cultures of XL1-blue MRF' grown in LB supplemented with 0.2% maltose and 10 mM MgSO<sub>4</sub> and 20 ml XLOLR cells (Pharmacia) grown in LB media were centrifuged for 5 min at 4'000 rpm and resuspended in 10 mM MgSO<sub>4</sub> to a final OD<sub>600</sub> = 1. Two-hundred µl of the XL1-blue MRF' cells were added to 250 µl of the SM-buffer containing the positive phages and 1 µl (10<sup>7</sup> pfu) ExAssist™ helper phage. This mixture was incubated 15 min at 37°C and 3 ml LB-broth were added and shaken another 3 hrs at 37°C. The cultures were then heated for 15 min at 70°C, centrifuged during 15 min at 5'700 rpm, 4°C, and the supernatant containing the pBK-CMV phagemid filamentous phage was decanted into fresh tubes. Two-hundred µl XLOLR cells were mixed with 100 µl supernatant and incubated for 15 min at 37°C, 300 µl LB-broth were added and the culture was incubated for another one hr at 37°C. Two-hundred µl of this culture were plated on LB-plates containing 50 mg/l kanamycin overnight at 37°C. Colonies were picked and mini-preps (using the QIAprep Spin Miniprep kit, Qiagen AG, Basle, Switzerland) performed for plasmid purification.

For sequencing, subclones of sequential DNA segments were generated with a double-stranded nested deletion kit (Pharmacia LKB, Biotechnology AB, Uppsala, Sweden). Sequencing was done with the dRhodamine Terminator Cycle Sequencing Kit (Applied Biosystems, Foster City, CA, USA) according to the manufacturer's protocol using either T3 and T7 primers flanking the cloned inserts in pBluescriptII-SK<sup>-</sup> or customer-synthesized internal primers. All sequences were determined on both strands. Reaction products were analyzed on an ABI Prism 310 genetic analyzer (Applied Biosystems).

#### Sequence data analyses:

Sequence alignment and editing were performed by using the software Sequencher (Gene Codes Corporation, Ann Arbor, MI, USA). Comparisons of DNA sequences and their deduced amino acid sequences with EMBL/GenBank and NBRF databases were performed using the programs BLASTN, BLASTX and BLASTP (Altschul et al., 1990). Potentially antigenic segments of AcrV were determined using the software *ProtScale* (<http://www.expasy.ch/cgi-bin/protscale.pl>) (Bairoch et al., 1995) and the software *Coils output* ([http://www.ch.embnet.org/software/COILS\\_form.html](http://www.ch.embnet.org/software/COILS_form.html)) (Lupas et al., 1991). The molecular masses of the protein and its theoretical isoelectric pH (pI) were calculated by using ProtParam tool (<http://www.expasy.ch/tools/protparam.html>) (Gill and von Hippel, 1989). Transmembrane prediction of the protein were made by using Tmpred ([http://www.ch.embnet.org/software/TMPRED\\_form.html](http://www.ch.embnet.org/software/TMPRED_form.html)) (Hofmann and Stoffel, 1993).

## PCR amplifications and preparations of DIG-labeled gene probes:

Template DNA was produced either by extraction of genomic DNA or by preparation of lysates from bacterial colonies. Lysates were obtained by resuspending five colonies of the corresponding bacterial cultures in 200  $\mu$ l lysis buffer (100 mM Tris-HCl, pH 8.5, 0.05% Tween 20 (Merck), 0.24 mg/ml proteinase K (Roche Diagnostics, Rotkreuz, Switzerland) dissolved in pyrogen-free water, filtered through a 0.22  $\mu$ m low protein binding membrane filter) followed by subsequent incubation for 60 min at 60°C and 15 min at 97°C. Lysates were then cooled on ice and used as PCR templates.

PCR amplifications were performed with either a PE9600 or PE2400 automated thermocycler with MicroAmp tubes (Applied Biosystems). The reaction was carried out in a 50  $\mu$ l reaction mix (10 mM Tris-HCl, pH 8.3, 1.5 mM MgCl<sub>2</sub>, 50mM KCl, 0.005% Tween 20, 0.005% NP-40 detergent, 170  $\mu$ M of each deoxynucleoside triphosphate (dATP, dCTP, dGTP, dTTP), 0.25  $\mu$ M of each primer, 2.5 units *Taq* DNA polymerase (Roche Diagnostics)), and 100 ng of template DNA or 5  $\mu$ l lysate. For the production of DIG-labeled probes, PCR mixtures were supplemented with 40  $\mu$ M digoxigenin-11-dUTP (Roche Diagnostics). PCR conditions were as follows: 3 min at 94°C followed by 35 cycles of 30 s at 94°C, 1 min at the corresponding annealing temperature (Table 2), and 30 s at 72°C. In addition, an extension step of 7 min at 72°C was added at the end of the last cycle in order to ensure full length synthesis of the fragments.

Curing of type III secretion genes from *A. salmonicida*:

In order to study the segregation of the type III secretion genes in *A. salmonicida* strain JF2267, the strain was inoculated in LB-broth at a density of  $A_{600} = 0.08$  and incubated 2 ½ hrs at 19°C. Then the culture was split in two. One part was kept for continued growth at 19°C, while the other part was incubated at 22°C. Samples were taken at different time points from both cultures and spread on LB-agar medium. The plates were then incubated at 19°C for 24 hrs. Subsequently, colony blot hybridizations were performed using gene probes to determine the loss of specific genes.

## Pulsed-field gel electrophoresis (PFGE):

The bacterial strains *A. salmonicida* JF 2267 and JF2397 were grown on LB agar for one day at room temperature. Then bacterial suspensions in 10 mM Tris, 10 mM EDTA, pH 8.0, sterile, were prepared to a final OD<sub>600</sub> of 5. Three-hundred  $\mu$ l of 1.5% Sea Kem gold agarose (FMC Bioproducts, Maine, USA) in 100 mM Tris, 100 mM EDTA, pH 8.0, was added to 300 $\mu$ l

of bacterial cell suspension. Plugs were immediately poured in sterile moulds and kept on ice until hardened. The plugs were then incubated at 50°C overnight in sterile 1.5 ml 0.5 M EDTA, 1% N-lauroylsarcosin, 2 mg/ml proteinase K (Roche Diagnostics), pH 8.0, by shaking. The next day, the plugs were thoroughly washed 5 times over the whole day at room temperature in sterile TE buffer (10 mM Tris, 1 mM EDTA, pH 8.0) and stored in sterile 0.5 M EDTA, pH 8.0, at 4°C until further use. To digest the plugs they were first incubated in 4 x Buffer H (Roche Diagnostics) for 10 min at 22°C. Then the plugs were incubated at 37°C by shaking for 7 ½ hrs in 2 x Buffer H containing 40 U of *NotI* (Roche Diagnostics). They were then placed into the slots of a 1% Sea Kem gold agarose gel in 0.5 x TBE and sealed with 1% Sea Kem gold agarose. The gel was then equilibrated in 0.5 x TBE at 12°C using an Electrophoresis CHEF-DR® III system (BioRad Laboratories, Hercules, CA, USA). To separate *NotI* DNA fragments, the field was 6V/cm, having an angle of 120°, starting with 1 s and ending with 12 s. The duration of the PFGE was 14 hrs and it was performed at 12°C. The gel was stained 30 min at room temperature in water containing 0.5 µg/ml ethidium bromide, washed two times with water and analyzed under a UV-light. Additionally, the gel was further used for Southern-blotting.

#### Southern-blot analyses:

Southern-blotting was done by alkaline transfer onto positively charged nylon membranes (Roche Diagnostics) with an LKB 2016 VacuGene vacuum blotting pump (Pharmacia LKB). To depurinate the agarose gels they were incubated for 10 min in 0.25 M HCl, and subsequent transfer was performed with 0.4 M NaOH for 1 ½ hrs. After blotting, membranes were baked for 30 min at 80°C under vacuum. After at least one hr of prehybridization, hybridization was carried out in 5 x SSC (1x SSC in 0.15 M NaCl plus 0.015 M sodium citrate)-1% blocking reagent (Roche Diagnostics)-0.1% N-lauroylsarcosine sodium salt-0.02% sodium dodecyl sulphate (SDS) at 68°C overnight, using DIG-labeled DNA as probe. Membranes were washed under nonstringent conditions twice for 5 min each with 50 ml of 2x SSC-0.1% SDS per 100 cm<sup>2</sup> at 22°C, followed by medium-high-stringency washing twice for 15 min each with 50 ml of 0.2x SSC-0.1% SDS per 100 cm<sup>2</sup> at 68°C. The membranes were then processed with phosphatase-labeled anti-DIG antibody (Roche Diagnostics) according to the manufacturer's protocol. Signals were produced with chemiluminescent substrate (CSPD, Roche Diagnostics).

Pulsed-field gels were treated for Southern-blotting by using the same solutions as described above. To depurinate the agarose gels efficiently, they were incubated for 20 min in 0.25 M HCl, and then equilibrated for 20 min in 0.4 M NaOH. Transfer was performed for 3 hrs and the gels were treated as described above.

Expression and purification of His-tailed fusion protein AcrV:

Oligonucleotide primers used to amplify the whole *acrV* gene are given in Table 2. The PCR reactions were carried out as described above with the exception of using *Pwo* DNA polymerase (Expand Long Template PCR System kit, Roche Diagnostics) instead of *Taq* DNA polymerase and genomic DNA of *A. salmonicida* JF2267. The PCR products were purified by using the High Pure™ PCR Product Purification Kit (Roche Diagnostics) as described by the manufacturer's protocol. Then the *acrV* PCR product was cloned into pGEM-T vector (Promega, Madison, WI, USA), having 3'-T overhangs at the insertion sites, as described in the manufacturer's protocol and transformed into *E. coli* strains XL-1 Blue. The resulting plasmid was designated pJFFIVB873. The cloning of the PCR products into pGEM-T vector was used to provide efficient restriction of the subcloned fragments. Plasmid pJFFIVB873 was then digested with *EcoRI* and *NotI*, and the DNA fragment was inserted into the T7-promoter-based expression vector pETHIS-1 (Schaller et al., 1999). The resulting plasmid, pJFFETHISacrV4 was purified and controlled by DNA sequencing to assure the fusions with the vector's poly-His codons and then transformed into *Escherichia coli* BL21(DE3) cells (Novagen) for expression. Expression was induced by addition of 1 mM IPTG to cultures and incubation continued for another 3 h. The cells were sedimented by centrifugation at 3000 x g for 10 min, resuspended in 5 ml PN buffer (50 mM NaH<sub>2</sub>PO<sub>4</sub>, pH 8.0, 300 mM NaCl), sonicated with a microtip for 4 min with the power output control at 1 and a duty cycle of 50% (1 s pulses) in a Branson Sonifier 250 (Branson Ultrasonics, Danbury, CT, USA). Then guanidine hydrochloride was added to a final concentration of 6 M and was incubated overnight at 4°C on a shaker. The mixture was loaded onto a prewashed 2.5 ml bed volume Ni<sup>2+</sup> chelation chromatography column (Qiagen) and washed once more with 30 ml PNG buffer (50 mM NaH<sub>2</sub>PO<sub>4</sub>, pH 8.0, 300 mM NaCl, 6 M guanidine hydrochloride). Step elutions of the proteins were performed by adding 10 ml PNG buffer at each different pH (7.0, 6.0, 5.5, 5.0, and 4.5) and fractions of 1 ml were collected. The fractions were dialyzed and analyzed on 15% PAGE. The purified fusion proteins were eluted at pH 4.5.

#### Production of monospecific rabbit anti-AcrV antibodies and immunoblot analyses:

Monospecific, polyclonal antibodies directed against AcrV were obtained by immunizing rabbits subcutaneous with 80 µg of recombinant polyhistidine-tailed AcrV protein in 200 µl PN buffer and 150 µl NaCl (0.85%) mixed with 350 µl Freund's complete adjuvant (Difco Laboratories, Detroit, MI, USA) followed by a booster immunization with the same amount of protein in Freund's incomplete adjuvant (Difco) 3 weeks later. The animals were bled 22 d after the booster immunization according to standard protocols (Harlow and Lane, 1988).

#### Infection of fish cell cultures with *A. salmonicida*:

Rainbow trout (*Oncorhynchus mykiss*) gonad cells (RTG-2, ATCC CCL-55) were grown in 75 cm<sup>2</sup> tissue culture flasks (Techno plastic products AG, Trasadingen, Switzerland) at 22°C in minimum essential medium (GibcoBRL Life Technologies, Basel, Switzerland) supplemented with 2 mM L-glutamine (GibcoBRL), 1 x non-essential amino acids (GibcoBRL), 3 g/l sodium bicarbonate and 10% foetal bovine serum. Three days before infection the cells were trypsinized and 4 mio cells were seeded into a 25 cm<sup>2</sup> tissue culture flask. Monolayered RTG-2 cells were infected with *A. salmonicida* cells resuspended in phosphate buffered saline (PBS) pH 7.4 at a multiplicity of infection of 20:1 or 2:1 (bacteria/fish cells). As a control also 100 µl of pure PBS pH 7.4 were added to cultured fish cells. After 24 hrs of infection at 15°C the fish cells were photographed under a green filtered phase contrast microscope (Aixovert 100, Zeiss, Jena, Germany). To detach the cultured cells from the flask, the flask was shaken by hand. The suspended cells were centrifuged for 5 min at 4'000 rpm. Lysis of the fish cells was performed in 100 µl distilled water with two subsequent freeze thawing steps and verified by microscopy. The lysed fish cells were used for further analyzes on Western-blot.

#### Protection assay using rabbit antiserum AcrV:

RTG-2 fish cells were grown as described above. Two days before infection 20 mio of trypsinized RTG-2 fish cells were seeded into 24 well culture plates (1.9 cm<sup>2</sup>) (Techno plastic products AG, Trasadingen, Switzerland). Rabbit antiserum directed against AcrV as well as control preserum were decomplexed for 30 min at 56°C. A fresh culture of *A. salmonicida* (at end exponential growth phase) was washed and resuspended in PBS pH 7.4 and mixed with either preserum or anti AcrV antiserum at a ratio of 1:1, 1:10, 1:100, 1:1000 or 1:10'000. Bacteria were incubated with the serum at 18°C for 30 min. The opsonized bacteria were added to the fish cells in a ratio of 20:1 or 2:1 (bacteria/fish cells). After 21 hrs of infection at 15°C the fish cells were photographed as described before and inspected for morphological changes.

#### SDS-PAGE and immunoblot analysis:

Proteins were separated by polyacrylamide gel electrophoresis (SDS-PAGE) as described by Laemmli (Laemmli, 1970) using 15 % or 10 % polyacrid gels and transferred to a nitrocellulose membrane (BioRad Laboratories). For immunoblotting, Western-blot were blocked with 1% milk buffer for at least one hour and then incubated with the rabbit antiserum AcrV (1:2000) or with the rabbit preserum (1:1000) in milk buffer overnight at 4°C. The membranes were then washed thoroughly with water before phosphatase-labelled conjugate (Goat anti-Rabbit IgG (H+L) [cat. no. 075-1506], Kirkegaard & Perry, Gaithersburg, MD, USA) diluted 1:2000 in milk buffer was added. The reaction was visualized 90 min later by incubation with BCIP-NBT (Ausubel et al., 1999).

Cloning and sequence analysis of the *virA* locus of a type III pathway of *A. salmonicida*:

Analysis of *A. salmonicida* strain JF2267 with an array of broad range probes for detection of type III secretion pathways revealed a strong signal with the *lcrD* subset of the probes, indicating the presence of a new type III secretion pathway. Subsequent Southern-blot analyses showed a 4.8 kb fragment of *SacI-SalI* digested genomic DNA of strain JF2267 reacting with the *lcrD* probe. This fragment was cloned on vector pBluescriptII-SK<sup>-</sup> leading to plasmid pJFFIVB638 which was subsequently sequenced. DNA sequence analyses revealed the presence of eight open reading frames (ORF) (figure 1) which showed strong similarity to the genes encoded on the *virA* operon of the type III secretion pathway of *Yersinia pestis* and *Pseudomonas aeruginosa*. In analogy to the *Y. pestis* genes, we named them *acr1*, *acr2*, *acr3*, *acr4*, and *acrD* (*Aeromonas calcium response* (Fig. 1)). They are located on a single operon followed by a transcription termination signal similar to the *virA* operon of *Y. pestis*, *Y. enterocolitica* and *Pseudomonas aeruginosa* (Boland et al., 1996; Iriarte and Cornelis, 1999; Plano et al., 1991; Cornelis, 1998; Yahr et al., 1997a). The similarities of the genes *acr1*, *acr2*, *acr3*, *acr4* and *acrD* with the analogues in *Y. enterocolitica* and in *P. aeruginosa* are given in Table 2. Downstream *lcrD* we identified a locus with a canonical promoter sequence followed by further genes named *acrR*, *acrG*, and *acrV* on a separate operon (Fig. 1) according to the corresponding genes in *Y. pestis* (Table 3) (Barve and Straley, 1990; Skrzypek and Straley, 1993; Nilles et al., 1998). The ORF of the putative *acrV* gene seemed to be incomplete on the 4.8 kb *SacI-SalI* fragment of pJFFIVB638, and represented only the 5'-half of the gene. The remaining part of *acrV* and part of *acrH* located downstream of *acrV* were cloned separately from the  $\lambda$  phage gene library of *A. salmonicida* as an overlapping clone which was obtained by screening the gene library using a gene probe for the 5'-half of *acrV* which was produced by PCR with primers AcrV-L and AcrV-R (Table 2). The resulting plasmid based on vector pBK-CMV was designated pJFFIVB832. From this plasmid, a 0.9 kb *SalI* fragment containing the 3' end of *acrV* and part of the downstream gene *acrH* was subcloned on pBluescriptII-SK and designated pJFFIVB828.

Instability of the genes belonging to the type III pathway in *A. salmonicida*:

When we analyzed the different *A. salmonicida* strains with a specific probe for *acrD*, we discovered by using Southern blot hybridization that the *acrD* gene was present only in strain JF2267 but not in the derivative strain JF2397 which had undergone nine passages of subsequent single colony cloning isolation. Additionally, the type strain of *A. salmonicida*, ATCC 33658<sup>T</sup>, did not show a signal with the *acrD* probe. However, several *A. salmonicida* strains that were freshly isolated from salmon and trout with furunculosis did contain *acrD* (Table 4). These

results indicate that the type III secretion pathway of *A. salmonicida* may be lost easily. In order to get an estimate on the loss of the type III secretion genes, we have analyzed the kinetics of disappearance of *acrD* after a shift of growth temperature of strain JF2267 from 19°C to 22°C. Colony hybridization with the *acrV* probe revealed that in a fresh culture of strain JF2267, the *acrD* gene was present in all cells grown at 19°C. After the shift to 22°C, *acrD* was still present for further 5 ½ hrs, following which it was lost very rapidly within less than 1 hr (Fig. 2). Taking into account the generation time of 2 h for *A. salmonicida* under the given growth conditions, the *acrD* gene was lost within two generations. To analyze the loss of *acrD* further, undigested and *NotI* digested genomic DNA of *A. salmonicida* strain JF2267 and of the *acrD* deficient derivative strain JF2397 were submitted to pulse field gel electrophoresis (PFGE) and subsequent Southern blot hybridization with the *acrD* probe. PFGE analyses of total undigested DNA revealed the presence of two large plasmids in strain JF2267 while in strain JF2397 only one of the two plasmids was seen (Fig. 3). Digestion of the total DNA from these two strains with the rarely cutting enzyme *NotI* revealed the lack of a 84 kb band in strain JF2397 compared to JF2267 as the sole detectable difference (Fig. 3). Southern-blot hybridization of the DNA on this gels with the *acrD* probe confirmed the larger plasmid and the 84 kb *NotI* fragment of strain JF 2267 to contain *acrD* gene. Neither the remaining large plasmid in JF2397 nor any of its *NotI* fragments hybridized with the *AcrV* probe. This indicates that the type III secretion genes, or at least the *virA* operon thereof, are located on a large plasmid in the size range of 84 kb.

#### Presence of *acrD* in *A. salmonicida* strains:

In order to assess the presence of the *acrD* gene in various *A. salmonicida* strains, DNA samples extracted from *A. salmonicida* Type strain ATCC33658 and various field strains isolated from salmon or char were digested with restriction enzymes *SalI* and *SacI*, separated by 0.7% agarose gel electrophoresis, blotted onto nylon membranes and hybridized with the *acrD* gene probe. The Southern blot revealed the presense of the *acrD* gene on a 4.8 kb fragment in all strains except in the type strain ATCC33658, the laboratory strain JF2396 which was used for the type III secretion genes, and *A. salmonicida* strain MT44 known to be avirulent for trout. One field strain, # 24, showed a very weak hybridization signal indicating that the culture contains *acrD* only in a minor population of the cells (Table 1).

#### Infection of RTG-2 fish cells and protection of cell damage with anti-AcrV antiserum:

Freshly cultured *A. salmonicida* strain JF2267 was used to infect RTG-2 cells. After 24 hrs of incubation the fish cells were rounded up and also detached from the plastic support (figure 4A). In contrast, cells infected with *A. salmonicida* type strain ATCC 33658<sup>T</sup> or strain JF2397 (figure 4B and C), both known to be devoid of *acrD* and *acrV*, showed no morphological

changes at all in spite of a massive multiplication of the bacteria in the cultures. RTG-2 fish cells which were incubated with PBS buffer as control showed no morphological changes like the cells infected with the *acrD* and *acrV* deficient strains JF2397 or ATCC 33658<sup>T</sup> (figure 4D).

In order to study further the role of the newly detected type III secretion pathway in virulence of *A. salmonicida*, we incubated strain JF 2267 with monospecific polyclonal anti-AcrV antibodies prior to infection of RTG-2 fish cell cultures. When RTG-2 fish cells were infected with strain JF2267 that was incubated with rabbit anti-AcrV antibodies diluted 1:1 or 1:10, the characteristic morphological changes of the cells were reduced, significantly affecting only 20 % of the cells or less (Fig. 4E) compared to the infection with non-treated strain JF 2267 (Fig. 4A) or to the infection with JF 2267 that was pretreated with serum from the same rabbit taken before immunization (Fig. 4F). Titration of the anti-AcrV serum showed that protection of about 50% of the RTG-2 cells could still be reached with a serum dilution of 1:100, while further dilutions had no visible effect in protection.

#### Expression of AcrV in *A. salmonicida*:

The expression of AcrV in *A. salmonicida* strain JF2267 was assessed by immunoblots using AcrV-His antibodies. When *A. salmonicida* was grown under standard culture conditions in TSB medium, no AcrV protein could be detected from total cells nor from culture supernatant of strain JF 2267, nor in the control of strains JF2397 and ATCC33658<sup>T</sup>. However, when the cells are submitted to a low Ca<sup>2+</sup> response by chelating free Ca<sup>2+</sup> ions in the growth medium by the addition of 10 mM NTA, we detected AcrV with anti-AcrV antibodies in the pellet of JF2267 as a protein of about 37 kDa (Fig. 5) but not in strains JF2397 and ATCC33658<sup>T</sup>, which are both devoid of the *AcrV* gene (Fig. 5). No AcrV protein could be detected in the supernatants of cultures from strains JF2267, JF2396 and ATCC33658<sup>T</sup>, grown in Ca<sup>2+</sup> depleted medium.

When strain JF2267 was grown under standard culture conditions (containing free Ca<sup>2+</sup> ions) and then put in contact with RTG-2 cells at a ratio 2:1 (bacteria : cells) for 30 minutes, the AcrV protein could be monitored on immunoblots reacting with anti-AcrV, similar to cultures from Ca<sup>2+</sup> depleted medium.

#### Recombinant AcrV Vaccine Trial

(see Appendix A)

While particular elements, embodiments and applications of the present invention have been shown and described, it will be understood, of course, that the invention is not limited thereto, since modifications may be made by those skilled in the applicable technologies,

particularly in light of the foregoing description. The appended claims include within their ambit such modifications and variants of the exemplary embodiments of the invention described herein as would be apparent to those skilled in the applicable technologies

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## Appendix A

### Recombinant AcrV Vaccine Trial

#### Materials:

##### VACCINE FORMULATIONS:

1. The **AcrV** vaccine was formulated using recombinant, Histidine-tagged AcrV resuspended in 10 mM phosphate buffer, pH 7.0, to 112.5 µg/mL. Four parts of this protein solution were mixed with one part oil adjuvant for a final AcrV concentration of 90 µg/mL. The dose for testing was 0.1 mL, or 9 µg/fish.
2. The commercial comparator vaccine was serial 4-13 of the vaccine **MultiVacc4** (Bayotek International Ltd.)
3. The placebo (control) vaccine consisted of phosphate buffered saline(**PBS**) (10 mM phosphate, 150 mM NaCl, pH 7.2).
4. All vaccines were maintained at 4°C until use.

#### Methods

##### TRIAL DESIGN:

Fish (rainbow trout *Oncorhynchus mykiss*) that have been determined to be pathogen free and are at least 15g in size are held for at least one-week pre vaccination for acclimation purposes. During the acclimation period the fish are offered 1% body weight in salmonid fish food every day, however they are denied food 24 hours pre and post-vaccination.

At least 50 fish are vaccinated 0.1 mL of **AcrV vaccine** via intra-peritoneal (IP) injection, or 0.2 mL of the commercial vaccine **MultiVacc4**. At the same time a group of at least 50 fish from the same stock are mock vaccinated with 0.1 mL of **PBS**. Vaccinated fish are then held for a period of at least 350-degree days to allow specific immune response generation in an acclimation tank with a continuous flow of water at a temperature of 12-13°C. The fish are offered 1% body weight in salmonid fish food daily until 24 hours pre- challenge and post-challenge.

After at least 350-dgree days post vaccination 50 fish per group were challenged by IP injection with a pre-determined concentration of virulent *Aeromonas salmonicida*. The dosage depends on the source of the fish and the water temperature (this is determined empirically immediately prior to challenge of test fish). The identical procedure is performed with the placebo vaccinated control fish. The fish are observed daily for mortality for 21 days post challenge and the cause of mortality assessed and examined to ensure that mortality is attributed to the challenge organism. After 24 hours post-challenge the fish are again offered 1% body weight in salmonid fish feed daily. Tanks are maintained with a continuous flow of water at a temperature of 12-13°C. For a challenge series to be considered satisfactory; all challenge groups must meet the following criteria:

1. At least 70% of the non-immunized controls must die within 21 days of challenge.
2. A relative percent survival (RPS) of no less than 25% must be achieved for the challenge disease before a vaccine is considered even partially efficacious for this disease.

$$\text{RPS} = [1 - (\% \text{ mortality vaccinates} / \% \text{ mortality controls})] \times 100$$

Developed from: The Rules Governing Medicinal Products in the European Union, Volume VII, Guidelines for the testing of veterinary medicinal products. 1994. Specific Requirements for the Production and Control of Live and Inactivated Vaccines Intended for Fish. Section 3.2. Potency.

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RESULTS

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Group	% Mortality	RPS
PBS	82	-
AcrV	49	40
MultiVacc4	30	63

1. There was a strong challenge with 82% control mortalities.

Table 1  
*A. salmonicida* strains used in this study and presence of *acrD*

strain	origin	<i>acrD</i> <sup>a)</sup>
ATCC33658	American Type Culture Collection, Type strain	-
JF2267	Char ( <i>Savelinus alpinus</i> ), Switzerland	+
JF2396	Laboratory strain, derivative of JF2267	-
CC-23	Salmon, Norway	+
CC-24	Salmon, Norway	+/- <sup>b)</sup>
CC-27	Salmon, Norway	+
CC-29	Salmon, Scotland, UK	+
CC-30	Salmon, Canada	+
CC-34	Salmon, Canada	+
MT 44	Spontaneous non virulent mutant	-
CC-63	Salmon, Canada	+
CC-72	Salmon, Canada	+

a) as determined by Southern blot hybridization

b) very weak hybridization signal indicating that only a minor part of the population of the culture contains the *acrD* gene

Table 2.  
Oligonucleotide primers

Name	Sequence <sup>a</sup> 5' to 3'	Position <sup>b</sup>	Annealing temp. °C
AsIcrD-L <sup>c</sup>	GCCCGTTTTGCCTATCAA	1159-1176	60
AsIcrD-R <sup>c</sup>	GCGCCGATATCGGTACCC	2028-2011	60
AcrV-L <sup>c</sup>	TTCGTTCGGCTGGCTTGATGT	4144-4163	58
AcrV-R <sup>c</sup>	GAACTCGCCCCCTTCCATAA	4734-4715	58
AsacrVt-L <sup>d</sup>	<u>gggaattc</u> GATGAGCACAATCCCTGACTAC	4104-4125	57
AsacrVt-R <sup>d</sup>	<u>atgcggccgc</u> AAATTGCGCCAAGAATGTCG	5188-5169	57
AsacrVN'-R <sup>d</sup>	<u>tcgcgccgc</u> ACCCTTTACGCTGATTGTC	4555-4537	57
AsacrVC'-L <sup>d</sup>	<u>cggaattc</u> GTTGCGGGATGAGCTGGCAG	4554-4573	57
AsacrVC'-R <sup>d</sup>	<u>tcgcgccgc</u> ACTCGGCTTCTATGCCACTC	4987-4968	57

<sup>a</sup> Lowercase letters indicate nucleotides added to create restriction enzyme recognition sites (underlined) for cloning.

<sup>b</sup> Based on nucleotide sequence of *A. salmonicida* JF2267

<sup>c</sup> Primer used for gene probe preparation

<sup>d</sup> Primer used for amplification of gene *acrV*, *acrV-N*, and *acrV-C* respectively

Table 3  
A. salmonicida type III proteins compared to analogues in P. aeruginosa and in Y. enterocolitica.

Protein in A. salmonicida	Analogue in P. aeruginosa	Similarity / identity <sup>a)</sup>	Genbank access. nr.	Analogue in Y. enterocolitica	Similarity / identity <sup>a)</sup>	Genbank access. nr.	Proposed function
Acr1	Pcr1	80 / 60	AF010150	TyeA	83 / 69	AF102990	part of the translocation-control apparatus, required for selective translocation of Yops
Acr2	Pcr2	63 / 44	AF01050	SycN	77 / 62	AF102990	chaperone for YopN
Acr3	Pcr3	62 / 47	AF01050	YscX	69 / 54	AF102990	part of the type III secretion apparatus, secretion of Yop
Acr4	Pcr4	66 / 55	AF01050	YscY	64 / 52	AF102990	part of the type III secretion apparatus, secretion of Yop
AcrD	PcrD	90 / 82	AF01050	LcrD	90 / 82	X67771	inner membrane spanning protein of type III secretion
AcrR	PcrR	68 / 58	AF01050	LcrR	71 / 58	AF102990	
AcrG	PcrG	63 / 46	AF010149	LcrG	64 / 42	AF102990	regulation of low calcium response
AcrV	PcrV	50 / 35	AF010149	LcrV	53 / 37	X96797	regulation of low calcium response, sensor suppression of TNF $\alpha$ and Interferon $\alpha$ , protective antigen
AcrH	PcrH	78 / 65	AF010149	LcrH (SycD)	79 / 58	AF102990	regulation of low calcium response, chaperon for YopD secretion

<sup>a)</sup> given as % of similar / identical amino acids

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DNA sequence information

LOCUS A.salmonicida type III vir1 5678 bp DNA BCT 26-MAR-2001  
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 ACCESSION tmpseq\_1  
 VERSION  
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 ORGANISM Aeromonas salmonicida  
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 Aeromonas.  
 REFERENCE 1 (bases 1 to 5678)  
 AUTHORS Stuber,K. and Frey,J.  
 TITLE Detection of a novel type III secretion pathway in Aeromonas  
 Salmonicida and its impact in virulence  
 JOURNAL Unpublished  
 REFERENCE 2 (bases 1 to 5678)  
 AUTHORS Stuber,K. and Frey,J.  
 TITLE Direct Submission  
 JOURNAL Submitted (26-MAR-2001) Institute for Veterinary Bacteriology,  
 University of Berne, Laenggass-Strasse 122, Berne, BE 3008,  
 Switzerland  
 FEATURES Location/Qualifiers

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WO 02/40514

PCT/CA01/01589

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## SEQUENCE LISTING

<110> Frey, Joachim  
 Stuber, Katja  
 Thornton, Julian C.  
 Kuzyk, Michael A.  
 Burian, Jan

<120> Novel Type III Secretion Pathway in *Aeromonas Salmonicida*, and  
 Uses Therefor

<130> 31393-1

<140> PCT/CA01/01589  
 <141> 2001-11-15

<150> US 60/248,864  
 <151> 2000-11-15

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 35 40 45  
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 35 40 45  
 Thr Leu Leu Val Ala Leu Leu Lys Gln Gly Glu Gly Glu Ala Ala Leu  
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 Ala His Val Asp Gln Leu Met Gln Gln Gly Glu Ala Asp Gly Pro Leu  
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Gly	Val	Ile	Glu	Lys	Glu	Ser	Gln	Met	Phe	Gly	Ser	Met	Asp	Gly	Ala
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Ala	Leu	Tyr	Leu	Asp	Leu	Gly	Val	Pro	Phe	Pro	Gly	Ile	His	Leu	Arg
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Glu	Ser	Ala	Ser	Gln	Leu	Asp	Leu	Leu	Gly	Ile	Pro	Tyr	Glu	Glu	Gly
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Gln	Glu	Arg	Leu	Glu	Lys	Ser	Arg	Leu	Ala	Thr	Leu	Thr	Thr	Asp	Gln
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Ser	Tyr	Ser	Glu	Leu	Val	Lys	Glu	Ala	Gln	Arg	Ile	Ile	Pro	Leu	Gln
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Arg	Asn	Met	Arg	Ala	Ile	Leu	Glu	Ala	Met	Val	Glu	Trp	Gly	Gln	Lys
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 Tyr Leu Leu Asp Gln Gln Val Glu Glu Gln Leu Arg Gly Gly Ile Arg  
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 Ser Phe Leu Asp Gln Val Arg His Thr Val Gly Asp Leu Ala Gln Met  
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 Gln Asn Lys Pro Val Leu Ile Val Ser Met Asp Ile Arg Arg Tyr Val  
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 Arg Lys Leu Ile Glu Gly Asp Tyr His Ala Leu Pro Val Leu Ser Tyr  
                                   675                                  680                                  685  
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 Leu  
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 Gly His Phe Leu Tyr Gly Asn Val Asp Val Phe Arg Ser Ser Ser Leu  
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 Ser Ser Glu Arg Leu Gly Arg Phe Tyr Leu Arg Trp Thr Gly Ala Ser  
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 Glu Ala Pro Thr Glu Gln Val Ala Val Ala Glu Gln Glu Leu Leu Ala  
           50                                  55                                  60  
 Glu Ile Gln Arg Arg Gln Ala Leu Leu Pro Ala Gln Pro Gly Glu Gly  
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 35 40 45  
 Ala Asp Ser Ser Thr Ala Leu Ser Lys Glu Gln Leu Glu Lys Leu Leu  
 50 55 60  
 Ala Ala Tyr Leu Thr Asp Pro Ala Ser Ile Asn Gly Gly Trp Ala Met  
 65 70 75 80  
 Gly Gln Phe Lys Gly Gly Gln Asp Ala Ala Ile Ala Ala Ile Lys Gly  
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 Val Ile Glu Arg Gly Ala Lys Gln Thr Pro Pro Val Thr His Trp Thr  
 100 105 110  
 Ile Pro Glu Phe Met Leu Leu Ser Leu Ser Ala Leu Thr Met Glu Arg  
 115 120 125  
 Thr Asp Asp Asp Leu Ile Thr Thr Phe Thr Gly Val Met Met Phe Gln  
 130 135 140  
 Asp Asn Gln Arg Lys Gly Leu Arg Asp Glu Leu Ala Glu Met Thr Ala  
 145 150 155 160  
 Glu Leu Lys Ile Tyr Gly Val Ile Gln Ser Glu Ile Asn Gln Val Leu  
 165 170 175  
 Ser Ala Ala Ser Asn Gln Thr Phe Lys Thr Asn Phe Asn Leu Met Asp  
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 Tyr Lys Leu Tyr Gly Tyr Glu Ser Leu Ala Lys Phe Met Glu Gly Gly  
 195 200 205  
 Glu Phe Lys Leu Leu Ser Lys Met Phe Ser Asp Glu Gln Val Thr Lys  
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 Ala Gln Gln Asp Phe Thr Asn Ala Lys Asn Glu Leu Glu Asn Val Thr  
 225 230 235 240  
 Ser Thr Ser Leu Asn Pro Lys Ile Gln Ala Glu Ala Lys Thr Asp Tyr  
 245 250 255  
 Glu Arg Lys Lys Ala Ile Phe Glu Glu Ile Val Glu Thr Gln Ile Ile  
 260 265 270  
 Thr Leu Lys Thr Phe Leu Glu Ser Asp Leu Lys Lys Ser Gly Ala Met  
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 Ser Gly Ile Glu Ala Glu Tyr Lys Tyr Asp Lys Asp Asn Asn Lys Leu  
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&lt;211&gt; 159

&lt;212&gt; PRT

<213> *Aeromonas salmonicida*

&lt;400&gt; 9

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 Ala Gly Lys Trp Glu Asp Ala His Lys Ile Phe Gln Ala Leu Cys Met  
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Leu Asp His Tyr Glu Pro Arg Tyr Phe Leu Gly Leu Gly Ala Cys Arg  
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 Ala Met Leu Asp Leu Lys Asp Pro Arg Phe Pro Phe His Ala Gly Glu  
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CLAIMS:

1. An isolated protein selected from SEQ ID NO:1; SEQ ID NO:2; SEQ ID NO:3; SEQ ID NO:4; SEQ ID NO:5; SEQ ID NO:6; SEQ ID NO:7; SEQ ID NO:8; or SEQ ID NO:9.
- 5 2. An isolated nucleic acid fragment encoding a protein comprising an amino acid sequence selected from SEQ ID NO:1; SEQ ID NO:2; SEQ ID NO:3; SEQ ID NO:4; SEQ ID NO:6; SEQ ID NO:7; SEQ ID NO:8; or SEQ ID NO:9.
3. An isolated nucleic acid fragment comprising SEQ ID NO:10, or the complement thereof.
- 10 4. The isolated nucleic acid fragment of claim 2 or 3, wherein the nucleic acid fragment is optimized for expression in a selected suitable host micro-organism.
5. An immunogenic, immunological or vaccine composition comprising a pharmaceutically acceptable carrier and: (a) a polypeptide comprising SEQ ID NO:8; or (b) a polynucleotide encoding (a).
- 15 6. The composition according to claim 5, comprising a polypeptide comprising SEQ ID NO: 8.
7. The composition according to claim 5, comprising said polynucleotide.
8. The composition according to claim 5 or 6, wherein said polypeptide is fused at its N'-terminal, C'-terminal, or both, to at least one other polypeptide.
- 20 9. The composition according to claim 8, wherein said at least one other polypeptide is a T cell epitope or a B cell epitope.
10. The composition according to any one of claims 5 to 9, wherein the composition is encapsulated, adsorbed, or absorbed to an insoluble matrix.

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11. The composition according to any one of claims 5 to 10, wherein the composition further comprises an adjuvant.
12. The composition according to any one of claims 5 to 11, for use in reducing the susceptibility of fish to infection by a virulent strain of *Aeromonas salmonicida*.
- 5 13. An expression vector comprising a nucleic acid molecule encoding a polypeptide selected from SEQ ID NO:1; SEQ ID NO:2; SEQ ID NO:3; SEQ ID NO:4; SEQ ID NO:5; SEQ ID NO:6; SEQ ID NO:7; SEQ ID NO:8; or SEQ ID NO:9.
14. Use of Aeromonas calcium response V (AcrV) comprising the amino acid sequence of SEQ ID NO:8 or the DNA encoding the amino acid sequence of SEQ ID NO:8 in  
10 the manufacture of a diagnostic agent.
15. An antiserum that specifically binds to a recombinant Aeromonas calcium response V (AcrV) comprising the amino acid sequence of SEQ ID NO:8, for use in protecting fish from the toxic effect of a virulent strain of *Aeromonas salmonicida*.

FIGURE 1

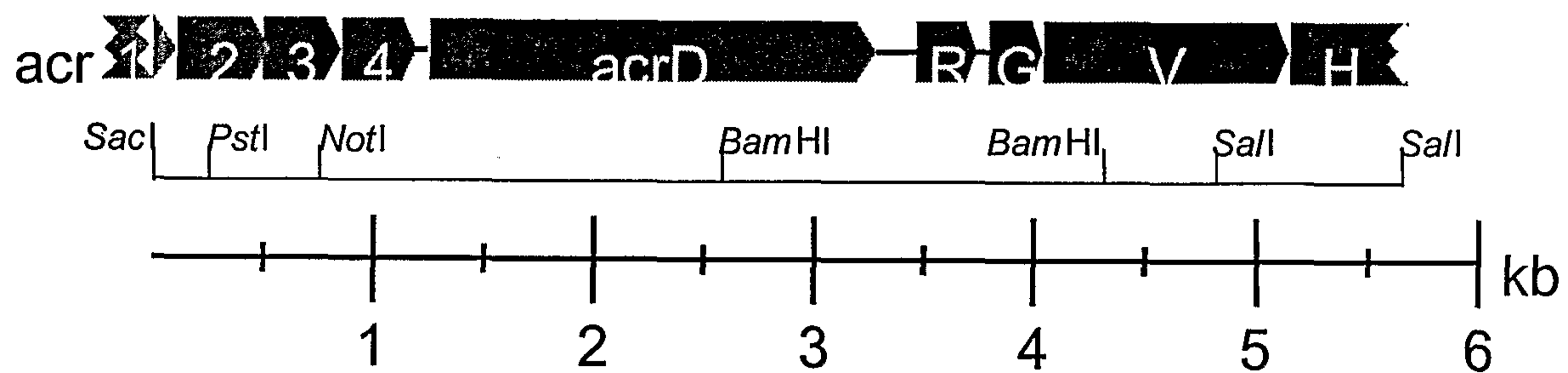


FIGURE 2

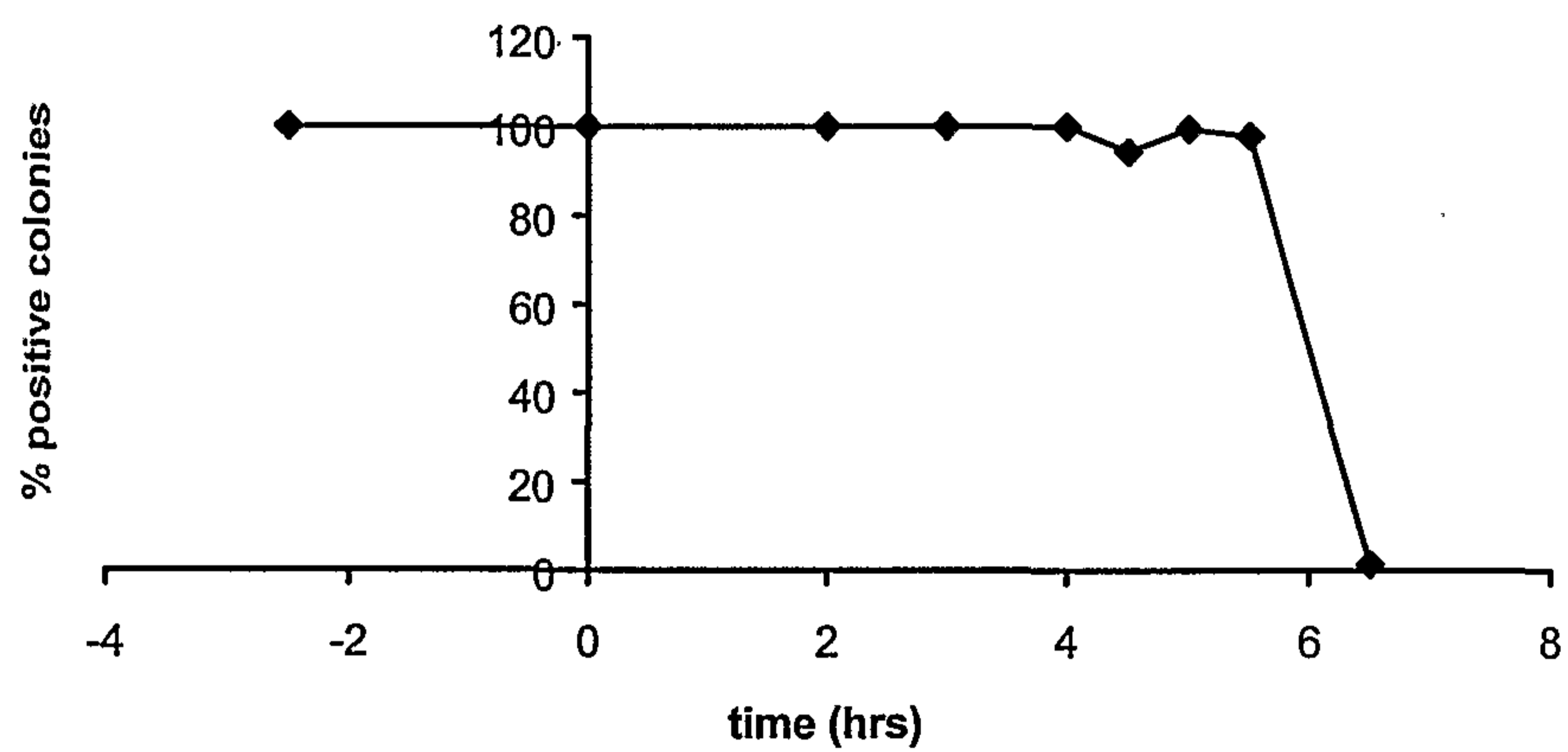


FIGURE 3

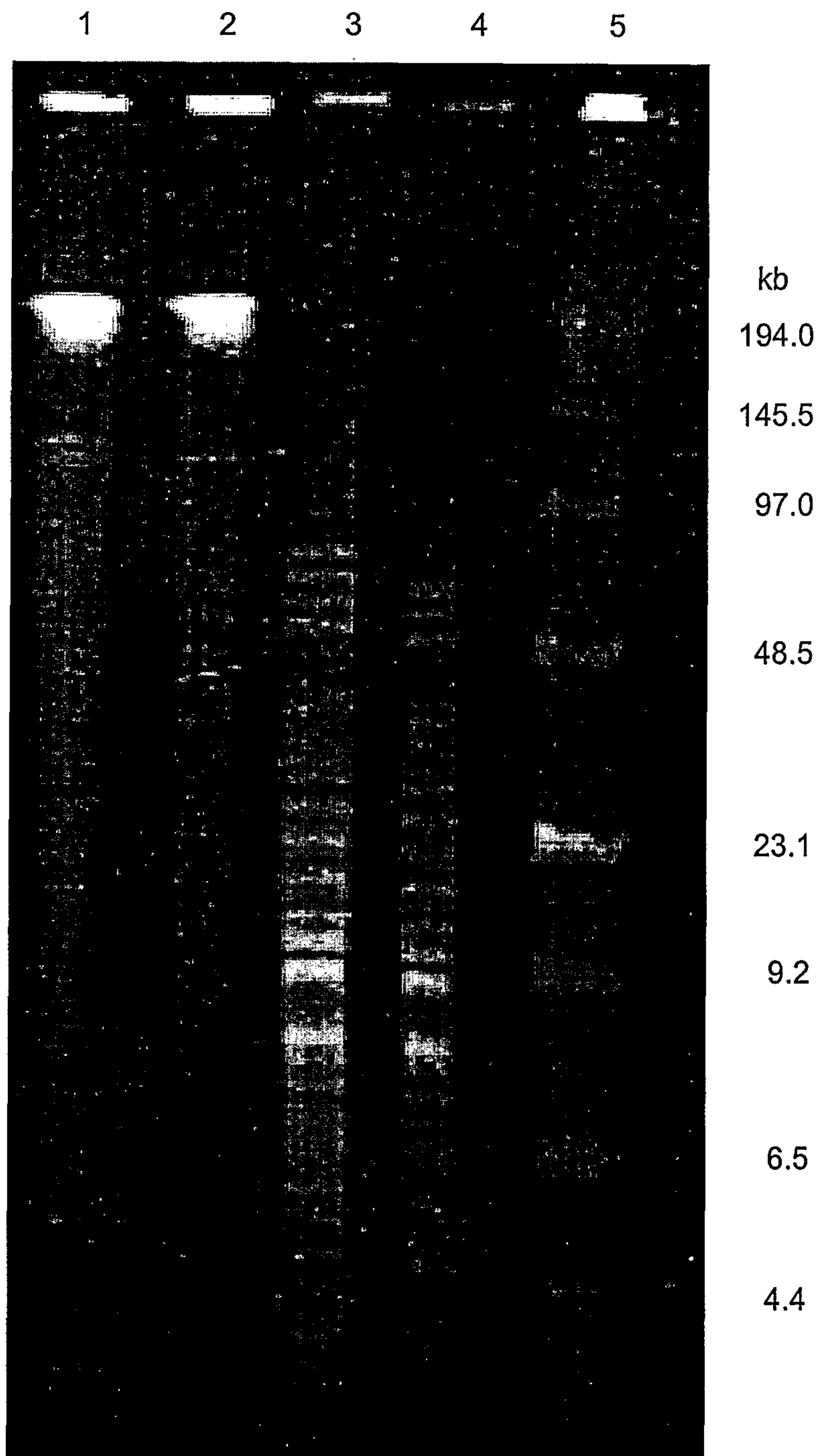
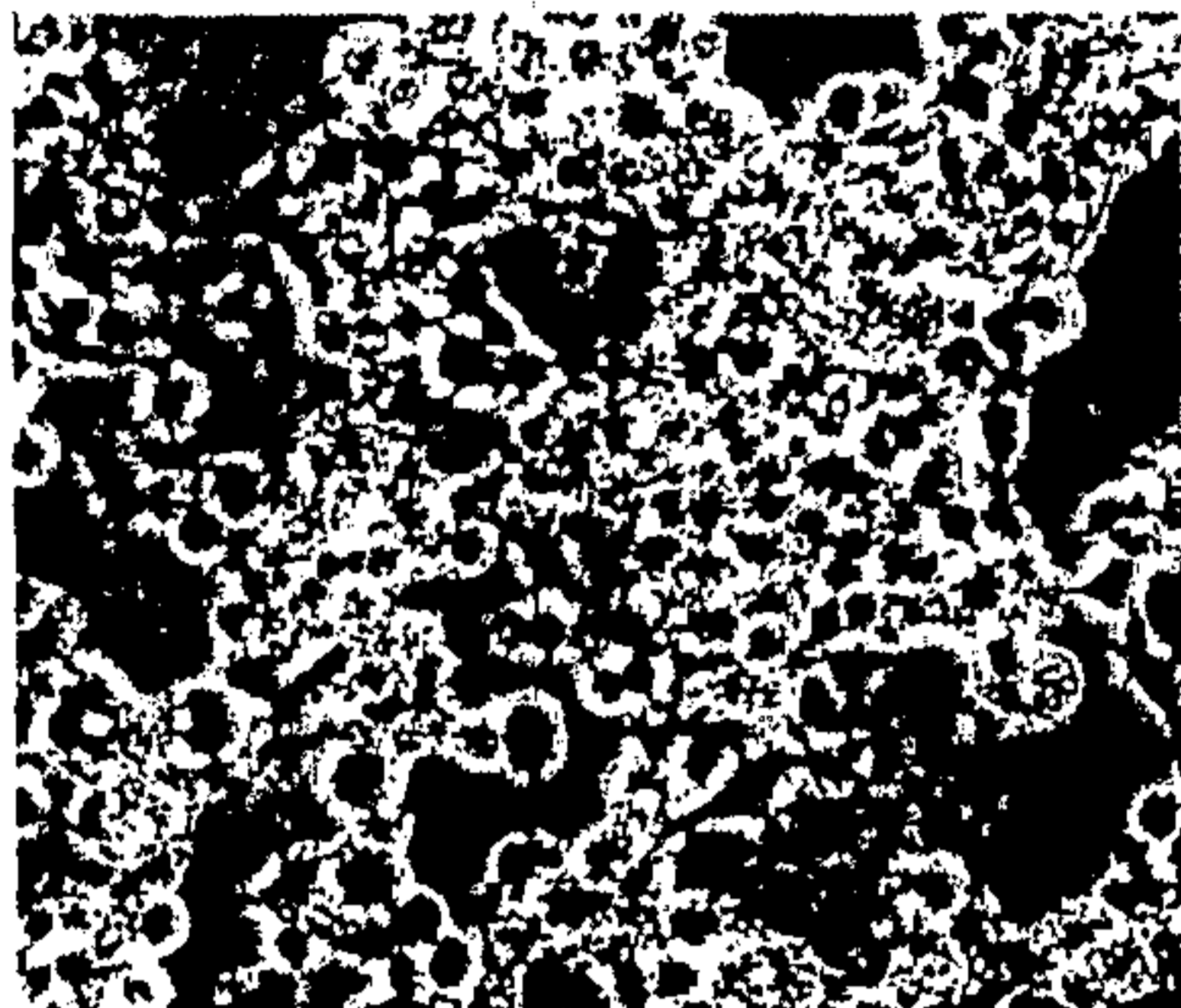
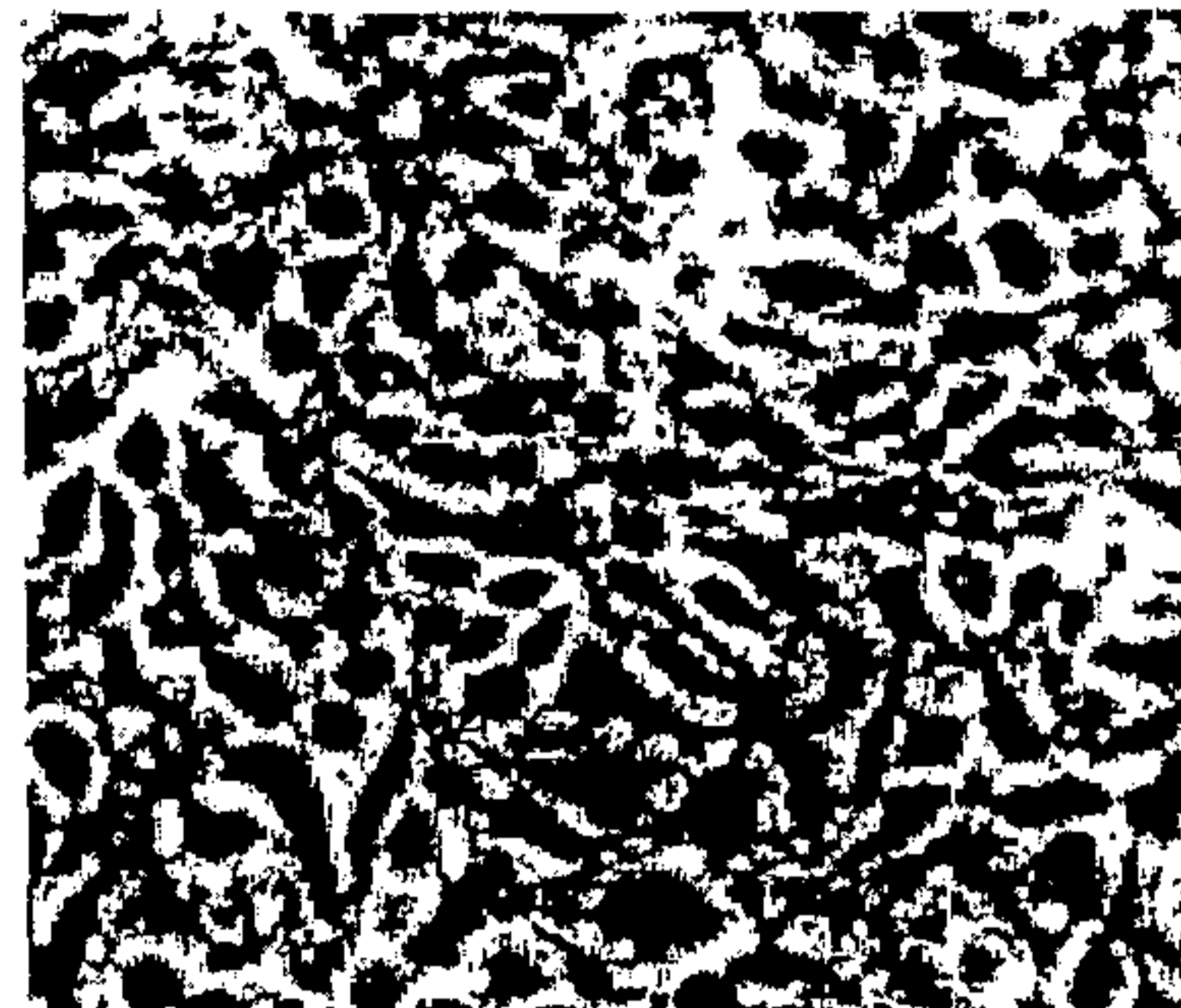


Figure 4

A



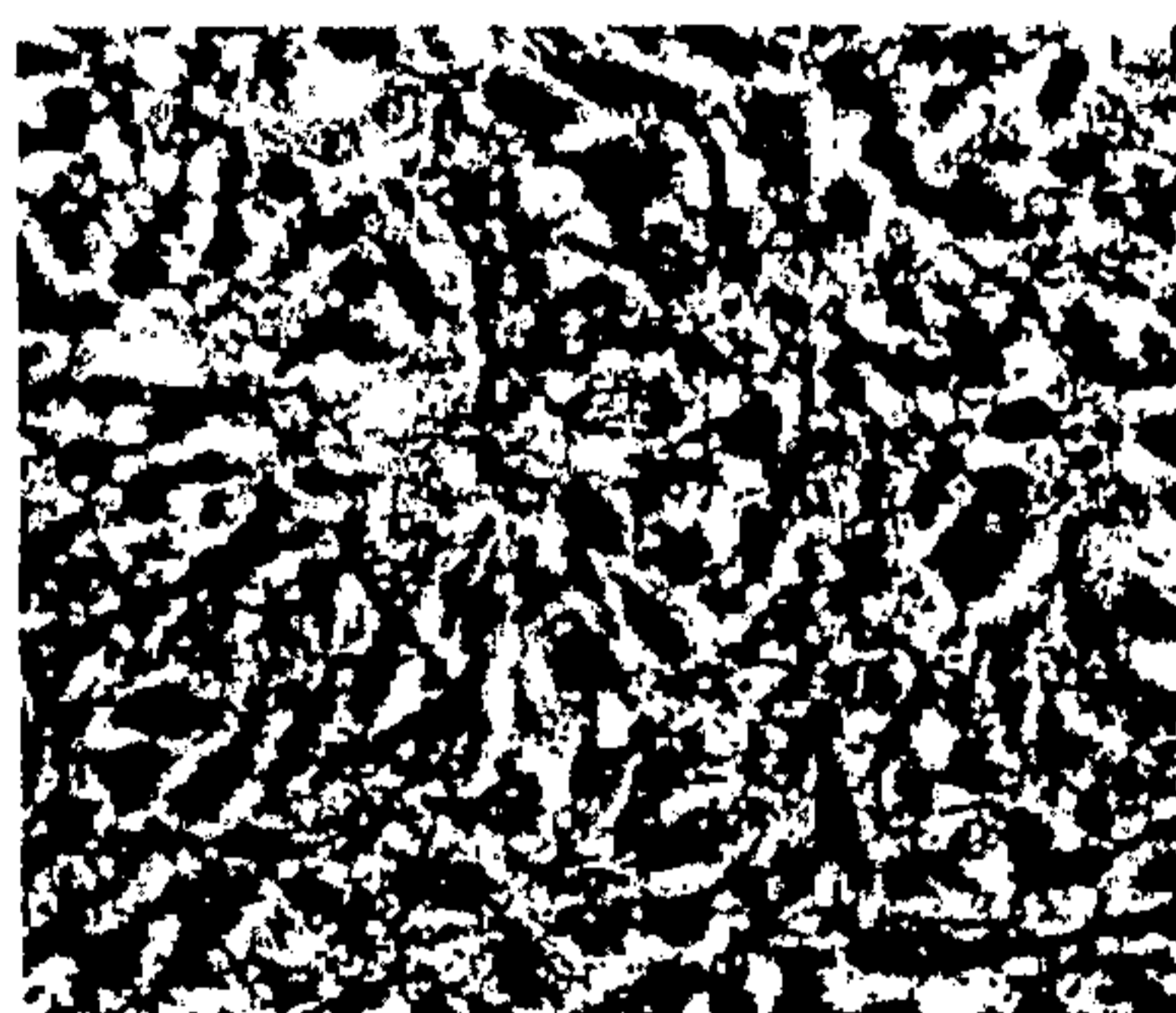
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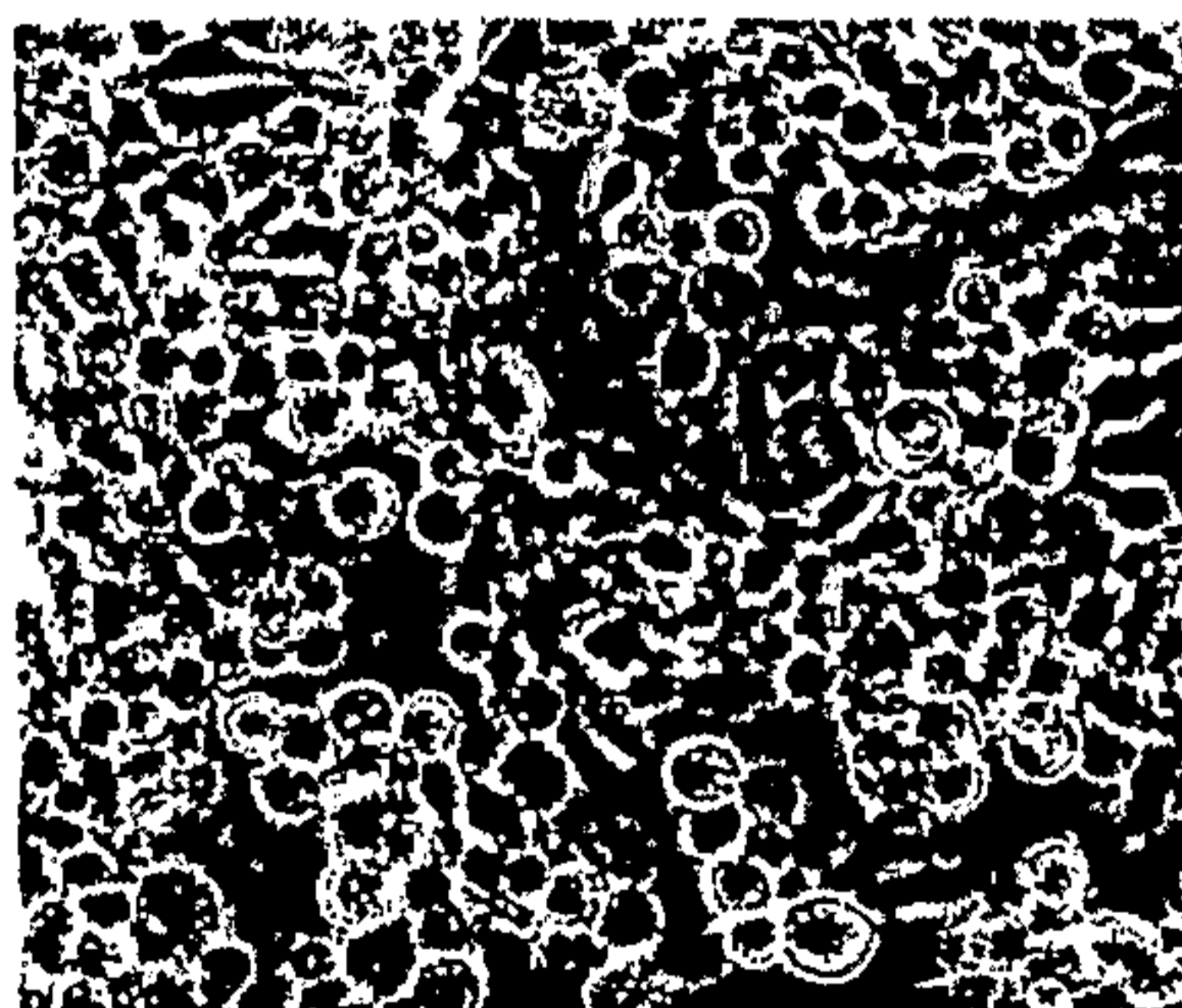
C



D



E



F

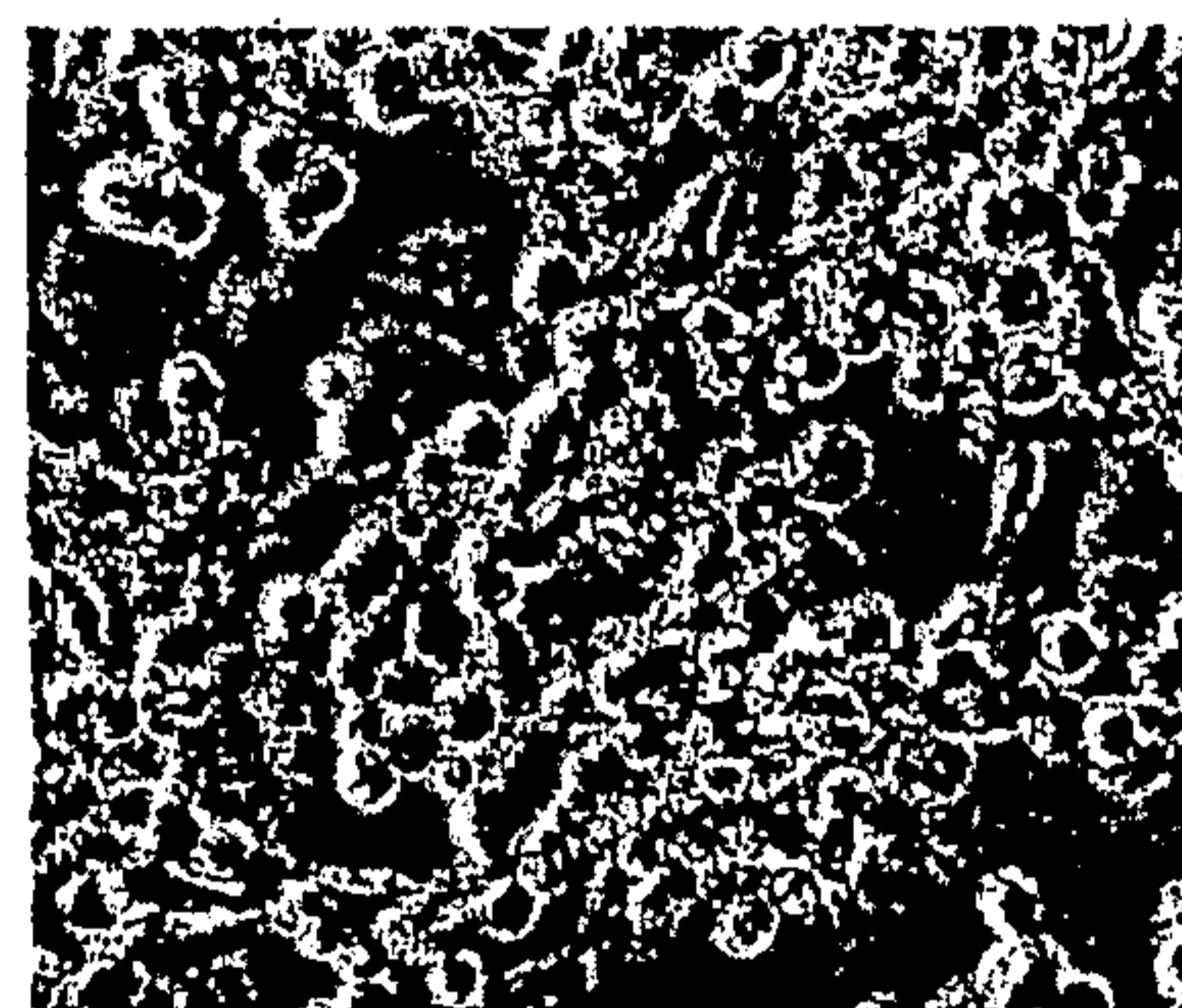


FIGURE 5

