Background and aims: Previous in vitro and in vivo studies have revealed an association between Helicobacter pylori infection and apoptosis in gastric epithelial cells. Although involvement of the Bcl-2 family of proteins as well as cytochrome c release has been demonstrated in H pylori induced cell death, the exact role of the mitochondria during this type of programmed cell death has not been fully elucidated. Therefore, we sought to determine whether or not Bax translocation and mitochondrial fragmentation occur on exposure of gastric epithelial cells to H pylori, resulting in cell death.

Methods: Experiments were performed with human gastric adenocarcinoma (AGS) cells, AGS cells transfected with the HPV-E6 gene (which inactivates p53 function), AGS-neo cells (transfected with the backbone construct), mouse embryonic fibroblasts (MEFs), and p19ARF null (ARF⁻/⁻) MEFs. Cells were incubated with a cag positive H pylori strain for up to 24 hours, lysed, and cytoplasmic and mitochondrial membrane fractions were analysed by western blot for Bax translocation.

Results: Bax translocation was detected in AGS, AGS-neo, and normal MEF cells after exposure to H pylori for three hours, but not in ARF⁻/⁻ MEFs cells. Translocation of Bax after H pylori incubation was also detected in AGS-neo cells (inactive p53 gene) but to a lesser degree than in AGS-neo cells. In parallel studies, the mitochondrial morphology of living cells infected with H pylori was assessed by confocal microscopy. Mitochondrial fragmentation was detectable after 10 hours of H pylori incubation with AGS cells and after seven hours with MEF cells. In wild-type MEFs, mitochondrial fragmentation was significantly increased in comparison with ARF null MEFs (43% v 10.4%, respectively). Furthermore, mitochondrial depolarisation and caspase-3 activity were initiated within four hours in cells incubated with H pylori, and these events were inhibited by forced expression of Bcl-2.

Conclusions: These data suggest that during H pylori induced apoptosis, Bax translocates to the mitochondria which subsequently undergo depolarisation and profound fragmentation. Functional ARF and p53 proteins may play an important role in H pylori induced mitochondrial modification.
patients.7 The Bcl-2 family, particularly Bcl-X L, are major mediators of the cell death pathway leading to the irreversible efflux of cytochrome c.25 Bax, Bcl-2, and Bcl-X L, contain a carboxy terminal hydrophobic domain that has been presumed to function as a membrane anchor domain.26

Experiments have indicated that Bax translocates from the cytoplasm to the mitochondrial membrane on activation of apoptosis and that Bax is a good candidate for mediating release of mitochondrial proteins.27 Therefore, we set up the following experiments to study the role of Bax in altering mitochondrial dynamics in gastric epithelial cells undergoing apoptosis after exposure to H pylori.

H pylori induced apoptosis is associated with an increase in Bax expression in both gastric biopsies from patients colonised with H pylori and in vitro.27 Konturek et al showed induction of apoptosis with evidence of Bax upregulation and Bcl-2 downregulation in H pylori positive duodenal ulcer patients.7 The Bcl-2 family, particularly Bcl-X L, are major antiapoptotic factors. Bax is a proapoptotic factor which may cross talk with p53.22 Bax redistributes from the cytoplasm to the mitochondria during cell death.28 Moreover, studies have shown that H pylori mediated apoptosis may occur through several pathways involving activation of p53,4 the death receptor Fas, and the death ligand tumour necrosis factor z.29 30 Levels of p53 protein are tightly controlled within eukaryotic cells. The rise in p53 protein levels, in response to cellular stress or DNA damage leading to apoptosis, is frequently a post-translational event resulting from decreased degradation. Break down of p53 can occur through its binding to MDM2, which targets p53 for ubiquitin proteosomal degradation.31 32 p19ARF (p14ARF in humans) is upstream of p53 and when bound to p53 inhibits MDM2 mediated degradation of p53.33 34 ARF can also bind p53 and enhance its transcriptional activity. Thus activation of p14ARF can promote p53 mediated apoptosis within eukaryotic cells. We have recently shown that p53 sensitises cells to apoptosis induced by H pylori.35 Also, our experiments showed involvement of ARF in stabilising p53 in cells exposed to H pylori.36

The relationship between H pylori induced apoptosis with ulcer and cancer is not very clear. It is possible that cancer may result from Bcl-2 overexpression in the presence of an inactive Bax (possibly through mutation). Pathways that H pylori infection uses for inducing apoptotic host cell mechanisms are still unknown. Mitochondria disintegration and dynamic changes in apoptotic cells have been reported.37 Fragmentation of mitochondria has been observed on Bax overexpression during apoptosis.38 The objectives of this study were to determine if there are dynamic changes in mitochondria in gastric cells exposed to H pylori, and to elucidate whether or not p53 is involved in mitochondrial modification induced by H pylori. These experiments demonstrated that on H pylori incubation, Bax translocates to the mitochondria followed by membrane depolarisation, and mitochondrial fragmentation. These phenomena are reduced in cells lacking functional wild-type p53. The reduction in Bax translocation in cells lacking p53 varies between cell types. P53 cross talk with Bax in these cells may influence cell death through mitochondrial fragmentation but it is not critical as gastric cells that lack wild-type p53 still undergo apoptosis.

**MATERIALS AND METHODS**

**Cell culture**

A gastric adenocarcinoma cell line (AGS) purchased from the American Type Culture Collection (Manassas, Virginia, USA) was used for these experiments. AGS cells were cultured in Dulbecco’s modified Eagle’s medium (DMEM) supplemented with 10% fetal bovine serum without antibiotics. Cells were incubated in 5% CO2 at 37°C in humidified air. Mouse embryonic fibroblasts (MEF) were cultured in DMEM supplemented with 10% fetal bovine serum (a gift from Dr Karen Vousden, Frederick, Maryland, USA).

**Infection and transfection of cell lines**

**Retroviral infection of AGS cells**

AGS cells were grown to 50% confluency in a 100 mm culture dish. Medium was removed and replaced with 3 ml of 4 μg/ml polybrene and 1 ml of virus stock (human papillomavirus (HPV) type 16 containing the E6 gene or an empty vector, Neo). After incubating AGS cells with virus for two hours, at 37°C, an additional 5 ml of culture medium with polybrene were added to the culture dish for another five hours of incubation. Cells were then rinsed with phosphate buffered saline (PBS) and 10 ml of medium without polybrene were added. On the second day, cells were split 1/10 to 1/200 in order to isolate individual colonies. On the third day, medium was replaced with medium containing G418 at a concentration of 400 μg/ml for selection. Stable colonies (AGS-E6 and AGS-neo) were isolated and used in these experiments.

**Transient transfections of AGS, AGS-E6, and AGS-neo**

Bcl-2 with H pylori was a gift from Dr Carlo Croce, Thomas Jefferson University) were performed using Fugene 6 (Roche, Indianapolis, Indiana, USA) following the manufacturer's instructions using 2.0 μg of mito-GFP (Clontech Laboratories, Inc., Palo Alto, California, USA) per chamber.

**Confocal microscopy**

AGS and MEF cells, respectively, were grown in 4.3 cm2 chamber slides (two well Lab-Tek chambered coverslip system; Nalge Nunc Inc., Naperville, Illinois, USA) and transfected with Lipofectamine 2000 transfection reagent (Invitrogen, Carlsbad, California, USA) according to the manufacturer's instructions using 2.0 μg of mito-GFP (Clontech Laboratories, Inc., Palo Alto, California, USA) per chamber.

**H pylori culture**

*Cag* positive *H pylori* strain J117 (a gift from Dr Timothy Cover39) was cultured on trypticase soy agar with 5% sheep's blood (Curtin Matheson, Jessup, Maryland, USA) with Skirrow's selective antibiotic supplement (Prolab Inc., Scarborough, Canada) at 37°C in a CO2/O2 water jacketed incubator (Forma Scientific, Marietta, Ohio, USA) under microaerophilic conditions (10% CO2, 7.5% O2, 82.5% N2). *H pylori* were added to cells at a bacteria:cell concentration of 100:1, based on previous reports that *H pylori* reproducibly induces apoptosis in AGS cells at this ratio.40 Cultures were maintained for three days prior to passing; bacteria were used between passages 5 and 15 for these experiments to ensure that the bacteria were able to readily adhere to AGS cells. Adherence was visualised using microscopy.

**Mitochondrial isolation and Bax translocation analysis**

AGS, AGS-E6, or AGS-neo cells were incubated with *H pylori* for three and six hours and then assayed for Bax translocation to the mitochondria. Lysis of cells for mitochondrial protein extraction was performed in isotonic buffer (200 mM mannitol, 70 mM sucrose, 1 mM EGTA, 10 mM HEPES, pH 6.9) by dounce homogenisation. Unbroken cells, nuclei, and heavy membranes were pelleted at 1000 g for five minutes and discarded. The mitochondrial enriched fraction was then produced by pelleting at 12 000 g for 20 minutes.
Bax translocation by *H. pylori*

The pellet was then washed briefly in alkaline wash buffer (0.1 M Na₂CO₃, pH 11.5) to separate peripherally associated (alkali sensitive) mitochondrial proteins from membrane integrated (alkali resistant) mitochondrial proteins and centrifuged. The pellet (containing the membrane integrated proteins) was then resuspended in RIPA lysis buffer (1× PBS, 1% Nonidet P-40, 0.5% sodium deoxycholate, 0.1% sodium dodecyl sulphate) with protease inhibitor cocktail (Calbiochem, San Diego, California, USA) and used for immunoblotting.

For detection of Bax and cytochrome c oxidase protein (cytochrome c oxidase, subunit IV, detection was employed as a control to demonstrate that mitochondrial protein fractionation was successfully achieved) by western blot, equivalent samples (20 μl containing approximately 20 μg protein) were separated by sodium dodecyl sulphate-polyacrylamide gel electrophoresis (SDS-PAGE) on 12% Tris glycline gels (Invitrogen) and transferred to 0.2 mM polyvinylidene difluoride membranes (Invitrogen). Blots were probed with a rabbit polyclonal antiserum specific for the amino terminal of Bax (N20; Santa Cruz, California, USA) or with a mouse polyclonal antibody specific for cytochrome c oxidase (Research Diagnostics, Flanders, New Jersey, USA), followed by the appropriate secondary antibodies conjugated to horseradish peroxidase (Santa Cruz) and then visualised by ECL kit (Pierce, Rockford, Illinois, USA) following the manufacturer's protocol.

**Measurement of mitochondrial membrane potential, viability, and caspase activity**

To measure mitochondrial membrane potential (∆Ψₘ), AGS, AGS-E6, or AGS-neo cells (1×10⁶ cells/ml) were resuspended in a 10 μg/ml solution of the cationic lipophilic dye tetramethylrhodamine ethyl ester (TMRE) (Molecular Probes, Eugene, Oregon, USA). For estimation of ∆Ψₘ, cells were incubated with 100 nM TMRE for 15 minutes at room temperature in PBS. After incubation, cells were immediately analysed by flow cytometry. Dead cells were excluded by forward and side scatter gating. Data were accumulated by analysing an average population of 20 000 cells. TMRE fluorescence was detectable in the PI channel (red fluorescence, emission at 590 nm). Caspase-3 activity was measured using PhiPhiLuxG1D2 kit (Calbiochem), a peptide substrate for caspase-3, which when cleaved emits green fluorescence using PhiPhiLuxG1D2 kit (Calbiochem), a peptide substrate for caspase-3, which when cleaved emits green fluorescence (excitation, 505 nm; emission, 530 nm). Caspase-3 activity was measured by analysing an average population of 20 000 cells. TMRE fluorescence was detectable in the PI channel (red fluorescence, emission at 590 nm). Caspase-3 was assayed by flow cytometry. Propidium iodide (PI) staining of non-viable cells was performed by incubation with 1 μl/10⁶ cells of PI solution (2 mg/ml in PBS) for >5 minutes. Stained cells were analysed by flow cytometry with excitation at 488 nm and emissions at 550 nm.

**Confocal microscopy and mitochondria fragmentation**

Cells (gastric and MEF cells) were overlaid with culture medium with or without *H. pylori* and incubated for up to 10 hours. Two well chamber slides which allow parallel and comparative imaging of two separately transfected cell populations under identical experimental conditions were used throughout the study. To prevent cell detachment and to better maintain cellular morphology, cells were pretreated with the caspase inhibitor Z-VAD-fmk (25 μM; Alexis Biochemicals, San Diego, California, USA) and 10 μM HEPES buffer (pH 7.0). Quantitative experiments have shown that there is no difference in the mitochondrial fragmentation rate of Z-VAD-fmk pretreated cells compared with controls. Images prior to and at given time points after *H. pylori* exposure were collected under thermostated conditions (37°C) using an Olympus Fluoview confocal microscope (FV300-IX70) with an 60× UPlan apochromatic objective (Olympus, Melville, New York, USA). The 488 nm line of an argon laser was used for fluorescence excitation of enhanced GFP. After acquisition, images were processed using Flouview and Photoshop software.

All experiments aimed at assessment and quantification of mitochondrial phenotypes were repeated at least twice independently. Typically, approximately 150 randomly selected cells were assessed per single experiment. A mutant form mitochondrial phenotype after *H. pylori* incubation was scored when at least 90% of the tubular mitochondria were disintegrated.

**RESULTS**

*H. pylori* mediated Bax translocation

*H. pylori* is a known inducer of cell death but the particulars of this death pathway are not fully understood. To begin to dissect how *H. pylori* triggers cell death, we analysed mitochondrial translocation of the death protein Bax. Mitochondrial translocation of Bax can be observed within three hours of incubation of *H. pylori* with AGS cells (fig 1). Next, we asked if mitochondrial translocation of Bax was H pylori dependent on ARF and p53, AGS-E6 (lacking functional p53), AGS-neo (control), and AGS (wild-type p53) cells were incubated with *H. pylori* for three hours. HPV-E6 has been shown to efficiently target p53 for degradation through MDM2 independent mechanisms, and E6 expressing cells are unable to stabilise p53 in response to cell stress or DNA damage making them functionally p53 null.5 AP5 AGS-neo cells were used as a negative control as they carry the bacitracin vector without E6 which should have no effect on p53 function. Bax translocated to the mitochondria in both AGS and AGS-neo control cells (fig 2). Partial translocation of Bax to the mitochondria was observed in AGS-E6 cells which are p53 null (fig 2). We scanned and calculated the degree of Bax translocation in all of the cells treated and untreated with *H. pylori*. The level of Bax translocation in AGS, AGS-neo, and AGS-E6 treated cells were 2.4-, 2.2-, and 1.3-fold (p<0.05), respectively. Note that basal levels of mitochondrial Bax in uninfected AGS cells are higher in fig 2 compared with fig 1 due to differences in loading between experiments. However, this still does not account for all of the increase in mitochondrial Bax content in infected cells. These results suggest that *H. pylori* induces activation of...
Bax, targeting the mitochondrial membrane, and that this process involves p53 dependent and independent pathways.

In prior studies we have shown that mouse embryonic fibroblasts (MEFs) are as sensitive as AGS cells to H. pylori induced apoptosis. Also, ARF−/− and p53−/− MEFs are more resistant to H. pylori induced apoptosis than wild-type MEFs.

In additional experiments, MEFs from wild-type and ARF−/− mice were incubated with H. pylori for three hours. Bax translocated and integrated into mitochondrial membranes in ARF+/− MEFs, AGS, and AGS-neo (3-, 2.4-, and 2.2-fold, respectively) but not into ARF−/− MEFs, and to a minimum in AGS-E6 cells (1.3-fold), suggesting that ARF, and to some extent p53, contribute to activation of Bax. Cytochrome c oxidase used as an internal control confirms the loading and quality of the lysates.

Mitochondrial depolarisation is caused by H. pylori infection and is blocked by Bcl-2

Incubation of cells with H. pylori provokes profound damage to mitochondria. To further assess the death pathway targeting mitochondria, we measured mitochondrial membrane depolarisation as a marker of mitochondrial dysfunction, using the fluorescent dye TMRE. As shown in fig 3, mitochondria begin to depolarise within 4–5 hours of incubation with H. pylori, as measured by loss of fluorescence. Mitochondrial membrane potential decreases in p53 containing cell lines, AGS and AGS-neo, as well as in p53 null AGS-E6 cells. Hence there are also p53 independent death effects.

**Figure 2** Helicobacter pylori induced mitochondrial Bax translocation is dependent on ARF and partially on p53. Mouse embryonic fibroblasts (MEF) from either ARF+/− or ARF−/− mice, AGS, AGS-E6 (E6), and AGS-neo (NEO) cells were cocultured with H. pylori for three hours (+) or cultured in medium alone as a control (−). Cytosolic and mitochondrial extracts were loaded onto sodium dodecyl sulphate–polyacrylamide gels followed by immunoblotting for Bax and cytochrome c oxidase. Bax translocated was integrated into mitochondrial membranes in ARF+/− MEFs, AGS, and AGS-neo (3-, 2.4-, and 2.2-fold, respectively) but not into ARF−/− MEFs, and to a minimum in AGS-E6 cells (1.3-fold), suggesting that ARF, and to some extent p53, contribute to activation of Bax. Cytochrome c oxidase used as an internal control confirms the loading and quality of the lysates.

**Figure 3** Loss of mitochondrial membrane potential (ΔΨm) occurred in gastric cells treated with Helicobacter pylori, and mitochondrial membrane potential loss was inhibited by forced Bcl-2 expression. AGS, AGS-E6 (E6), or AGS-neo (NEO) cells (1 × 10⁶ cells/ml) were resuspended in 10 μg/ml tetramethylrhodamine (TMRE). After incubation, cells were immediately analysed by flow cytometry. Dead cells were excluded by forward and side scatter gating. Data were accumulated by analysing an average population of 20 000 cells. TMRE fluorescence was detectable in the PI channel (red fluorescence, emission at 590 nm). In parallel experiments, AGS, AGS-E6, or AGS-neo cells transfected with Bcl-2 (to inhibit apoptosis) were stained as explained above. Loss of ΔΨm was quantified by flow cytometry analysis of untransfected cells versus Bcl-2 transfected gastric cells after H. pylori treatment for the indicated time periods. Bcl-2 transfected cells exhibited a significantly reduced ΔΨm at four hours after H. pylori treatment (p < 0.05). In contrast, Bcl-2 transfected cells exhibited a much slower decline in membrane potential.
in these cells, induced by *H pylori*, targeting the mitochondria. To determine if mitochondrial damage mediated by *H pylori* is mediated by Bax, we transiently expressed the antiapoptotic protein Bcl-2 prior to incubation with *H pylori*. The balance between Bax and Bcl-2 is known to regulate apoptosis. As others have shown that Bcl-2 does not block Bax translocation but protects mitochondria from Bax mediated damage, we measured mitochondrial depolarisation in cells incubated with *H pylori*. Forced expression of Bcl-2 was able to protect the mitochondria of cells incubated with *H pylori* from depolarisation. Thus the apoptotic pathways induced by *H pylori* in AGS cells activate Bax, disrupt mitochondrial integrity, and are abrogated by Bcl-2.

### Fragmentation of mitochondria by *H pylori*

To test whether or not apoptotic cell death caused by *H pylori* was associated with changes in the mitochondrial phenotype, AGS, AGS-E6, and AGS-neo cells were transiently transfected with a green fluorescent protein/cytochrome c oxidase subunit VIII fusion construct (mito-GFP) that specifically targets the mitochondrial matrix compartment. At 12 hours after transfection, cells were incubated with *H pylori* at 100 bacteria per cell and mitochondrial morphology of living cells was subsequently assessed by confocal microscopy. Although confocal imaging of the mitochondrial network of AGS is hampered by the fact that these comparatively small cells round up very early during cell death, profound changes in mitochondrial morphology were readily observed at 10 hours after infection. More than 70% (5%) of AGS cells showed a fragmented mitochondrial phenotype (A'). In contrast, in AGS-E6 cells with inactivated p53 function, less than 15% (5%) of cells underwent mitochondrial fragmentation under identical experimental conditions (C').

![Figure 4](https://www.gutjnl.com/gut03024372)  
*Figure 4* AGS, AGS-E6, and AGS-neo cells transfected with mito-green fluorescent protein (GFP) were treated with *Helicobacter pylori* and visualised by confocal microscopy. Mitochondrial morphology was assessed after *H pylori* treatment. At 10 hours of treatment, more than 70% (5%) of AGS cells showed a fragmented mitochondrial phenotype (A'). Comparable results were obtained in AGS-neo cells (B'). The typical reticulotubular mitochondrial phenotype of healthy AGS cells disintegrated into multiple small rounded organelles (A, A'). In contrast, in AGS-E6 cells with inactivated p53 function, less than 15% (5%) of cells underwent mitochondrial fragmentation under identical experimental conditions (C, C').

![Figure 5](https://www.gutjnl.com/gut03024372)  
*Figure 5* *Helicobacter pylori* induced mitochondrial fragmentation. ARF+/+ mouse embryonic fibroblasts (MEFs) and ARF−/− MEFs transfected with mito-green fluorescent protein (GFP) were treated with *H pylori* and visualised by confocal microscopy. Mitochondrial morphology of ARF−/− MEFs cells was assessed at seven hours after *H pylori* treatment by confocal microscopy. The gradual decrease in the percentage of cells featuring normal mitochondrial morphology was paralleled by an increasing percentage of cells exhibiting the punctiform phenotype. (A') ARF−/− MEFs undergoing profound changes in their mitochondrial phenotype during *H pylori* induced apoptosis are shown. In ARF+/+ MEF cells, the characteristic reticulotubular mitochondrial morphology (A) disintegrates into numerous round fragments of varying size (A'). In some cells, as exemplified by the bottom panel, the resulting punctiform mitochondria appear swollen, relative to the normally thin diameter of the mitochondrial tubules. (B) Mitochondrial morphology was also documented in mito-GFP transfected ARF−/− MEFs cells before (B) and after seven hours of *H pylori* treatment (B'). Mitochondria appear healthy and no obvious morphological changes were observed.
cells were cocultured with or without *H pylori* and AGS-neo as well as in the p53 null AGS-E6 cells (fig 6).

In ARF-null MEF cells (p53 function inactivated; fig 5), we transiently expressed the antiapoptotic protein Bcl-2 prior to incubation with *H pylori*. Caspase-3 cleavage and activity is known to be involved in *H pylori* induced apoptosis.44 As others have shown that Bcl-2 protects mitochondria from Bax mediated damage,41 42 we measured caspase-3 activity in *H pylori* exposed cells. Forced expression of Bcl-2 was able to inhibit caspase-3 activity in cells exposed to *H pylori* (fig 7). At 0 hours, 10–14% of cells were positive for caspase-3 activity. However, at four hours after *H pylori* exposure, caspase activity increased to 60% in AGS cells, to 39% in AGS-neo cells, and to 35% in AGS-E6 cells. Treated cells were protected by forced expression of Bcl-2 in all three gastric cell lines and caspase activity decreased to 14% at 24 hours (similar levels as untreated cells). Hence the death pathways induced by *H pylori* in AGS cells involves activation of caspase-3 and can be inhibited by the antiapoptotic protein Bcl-2.

**DISCUSSION**

In this study, we have shown that *H pylori* infection promotes apoptosis mediated through Bax that can be inhibited by forced expression of Bcl-2. As a consequence of *H pylori* infection, mitochondrial fragmentation results in subsequent Bax translocation, caspase activation, and cell death. Apoptosis is defined as an active physiological process of cellular self destruction with specific morphology and biochemical changes.43 Apoptosis and proliferation are tightly regulated processes within cells. Among apoptosis related genes, p53, Bax, and Fas are of particular importance. The involvement of the Fas pathway has been shown together with involvement of Bcl-2 proteins in *H pylori* induced apoptosis.44 45 46 P53 and p14ARF are well known for suppression of
Figure 7 Caspase-3 activity was inhibited in gastric cells with forced Bcl-2 expression treated with Helicobacter pylori. AGS, AGS-E6 (E6), or AGS-neo (NEO) cells were cocultured with or without H pylori for four hours. Caspase-3 activity was measured with a peptide substrate for caspase-3 which when cleaved emits green fluorescence (excitation, 505 nm; emission, 530 nm). Data were accumulated by analysing an average population of 20 000 cells by flow cytometry. In parallel experiments, AGS, AGS-E6, or AGS-neo cells transfected with Bcl-2 (to inhibit apoptosis) were stained as explained above. Caspase-3 activity was quantified by flow cytometry analysis of untransfected cells versus Bcl-2 transfected gastric cells after treatment for the indicated time periods. Bcl-2 transfected cells exhibited significantly reduced caspase-3 activity four hours after H pylori treatment (p<0.05). In contrast, untransfected cells exhibited much higher caspase-3 activity. Values represent the average of triplicate samples.

Bacteria other than H pylori may have the ability to activate host apoptotic processes in response to infection and inflammation. Bax translocation has also been demonstrated in Chlamydia psittaci infected cells where it was found to be independent of caspase activation. It is not clear whether activation of the caspase pathway is generally beneficial to the host or pathogen. Some pathogens, including Chlamydia trachomatis and Rickettsia rickettsii, do not induce apoptosis, which may allow these organisms to grow and persist intercellularly. Streptococcus pyogenes causes mitochondrial dysfunction that leads to release of cytochrome c from the mitochondria via Bax translocation.

Release of cytochrome c in response to H pylori is an early event in gastric epithelial cells. H pylori can cause stress signalling to transduce the mitochondria and cause the release of cytochrome c. Activation of Bax and its translocation to the mitochondria followed by membrane depolarisation, mitochondrial fragmentation, and cytochrome c release are associated with H pylori induced apoptosis, which is consistent with various studies demonstrating decreased levels of Bcl-2 and increased levels of Bak in AGS cells exposed to H pylori. When cytochrome c is released, it binds together with dATP and apoptosis activating factor-1 to procaspase-9, resulting in the activation of downstream caspases.

Previous publications confirmed cell death induction by H pylori in the presence and absence of the Cag pathogenicity island. However, the presence of the both cagA and vacuolating cytotoxin may be important factors in causing the severe damage of the human gastric mucosa produced by H pylori. While qualitative differences occur between cag positive and cag negative H pylori strains, most studies show no significant difference in the ability of these strains to induce apoptosis or to stimulate proapoptotic factors. Therefore, our experiments used only a cag positive strain. In prior experiments we have shown that H pylori induced apoptosis is associated with accumulation of p53 protein and a decrease in Bcl-2. In addition, we demonstrated that H pylori induced apoptosis activated caspase-8 and caspase-3 which in turn degrade poly adenosine ribose polymerase (PARP) and DNA fragmentation factor 45, consistent with the data reported here.

Several lines of in vitro evidence suggest that induction of caspase-8, -9, and -3 may play a role in the aetiology of H pylori associated ulcer disease and may be involved in early processes of gastric carcinoma. After H pylori infection, cytochrome c release from the mitochondria activates caspase-8, -9, and -3, as confirmed by cleavage of PARP. Different H pylori cytotoxic factors including vacA, lipopolysaccharide,
and/or the pathogenicity island may be important in Bax translocation and induction of cytochrome c from mitochondria which induces oligomerisation of Apaf-1, allowing activation of procaspase-9 to promote apoptosis.\textsuperscript{31} The antiapoptotic BCL-2 family of proteins are generally characterised by the presence of four conserved BH3 domains (BH1–4). Bak-BH3 peptide induces Bax conformational change in vitro only in the presence of BH1, BH2, and BH3) with BCL-2, and lack the fourth domain (BH4), which is unique to antiapoptotic proteins\textsuperscript{32},\textsuperscript{33}. In contrast, several other proapoptotic proteins share only a single domain (BH3) with BCL-2 and are designated as “BH3-only” proteins. BH3-only proteins serve as effectors of apoptotic signalling and connect the various apoptotic stimuli with core apoptotic machinery.\textsuperscript{31} Both BAX and BAK appear to exist in inactive conformations and are “activated” in response to various apoptotic stimuli and form multimeric complexes.\textsuperscript{31,34} Studies have led to the suggestion that both BAX and BAK constitute critical components of mammalian apoptosis machinery, and these multidomain proteins may be functionally overlapping.\textsuperscript{35} A recent study suggests that the multidomain proapoptotic proteins may not have fully overlapping functions in all cell types and that BAX may play a more important role in the apoptosis paradigms in human epithelial cancer cells.\textsuperscript{31} Therefore, Bax may play a critical role in H pylori apoptosis and the role of other effectors such as Bim remains to be investigated. In addition, metabolic damage due to loss of mitochondrial function may contribute to H pylori cell death.

Here, we demonstrated that forced expression of Bcl-2 not only blocks cell death but also inhibits caspase-3 activity. This indicates the significant mitochondrial involvement in H pylori induced cell death. It would be an oversimplification however to assume that the pathway leading from mitochondrial membrane permeabilisation to nuclear apoptosis relies exclusively on caspase activation. The death pathway is initiated at the mitochondria by release of cytochrome c, a process that can be inhibited by antiapoptotic proteins of the Bcl-2 family. Thus translocation of Bax to the mitochondria in cells infected with H pylori and subsequent mitochondrial fragmentation provide a direct link between infection and apoptosis induced by H pylori.

In many cell types, p53 function is known to be critical for the ability to commit programmed cell death. Therefore, our data obtained from p53 deficient AGS-E6 and ARF-null MEF cells (both of which showed reduced apoptosis associated changes in their mitochondrial phenotypes) show that both p53 dependent (more evident in MEFs) and p53 independent pathways can lead to mitochondrial fragmentation in response to H pylori induced cell damage. We conclude that during apoptosis induced by H pylori infection, the mitochondrial morphology in respective cell types switches from a reticulotubular to a punctiform mitochondrial phenotype, compatible with organelle fragmentation. In summary, H pylori induces Bax to translocate to the mitochondria resulting in membrane depolarisation and mitochondrial fragmentation. These phenomena are reduced in cells lacking wild-type p53. The reduction in Bax translocation in cells lacking p53 varies among cell types. P53 cross talk with Bax in these cells may influence cell death through mitochondria fragmentation, but this is not critical as cells that lack wild-type p53 still undergo apoptosis, although less frequently. Therefore, p53 is partially involved in the death process in gastric cells exposed to H pylori and alternative pathways are likely to play a role. Further studies are needed to identify bacterial factors responsible for stimulation of Bax translocation and/or p53 stabilisation that results in mitochondrial fragmentation and subsequent apoptosis.

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Bax translocation by H pylori


