

# Apoptotic Mitochondrial Dysfunction Induced by Benzo(a)pyrene in Liver Epithelial Cells

## Role of p53 and pH<sub>i</sub> Changes

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**ABSTRACT:** How pH<sub>i</sub> changes, more specifically alkalization, affect the apoptotic cascade has yet to be determined. The aim of the present work was to test the involvement of mitochondria in the apoptotic cascade triggered by benzo(a)pyrene [B(a)P] and to determine the role of pH<sub>i</sub> changes and p53 relative to mitochondria. Our results indicate that B(a)P-induced apoptosis might rely upon a p53-dependent and a pH-sensitive mitochondrial dysfunction.

**KEYWORDS:** benzo(a)pyrene; rat liver epithelial cell; apoptosis; mitochondria; intracellular pH; p53; reactive oxygen species

### INTRODUCTION

Polycyclic aromatic hydrocarbons (PAHs), such as benzo(a)pyrene [B(a)P], are responsible for important carcinogenic and apoptotic effects, whose mechanisms are still poorly understood. With respect to PAH-induced apoptosis, this phenomenon has been shown to require caspase<sup>1</sup> as well as p53 activation.<sup>2</sup> An important role for reactive oxygen species (ROS) production has been demonstrated in cell death induced by various chemicals.<sup>3</sup> Regarding this latter point, although PAHs, via metabolism through cytochrome 1A1, are well known to induce ROS production, a role for such species in the apoptotic cascade triggered by these compounds remains to be established. Besides ROS, cytoplasmic acidification has also been proposed as an important factor in apoptosis.<sup>4</sup> In this context, it is worth noting that we have shown previously that biphasic perturbations of H<sup>+</sup> homeostasis (i.e., early alkalization followed by late acidification) were elicited during B(a)P-induced cell death in the rat liver F258 epithelial cell line and that inhibition of those changes afforded a significant cell protection against B(a)P-induced toxicity.<sup>5</sup> However, how pH<sub>i</sub> changes, more specifically alkalization, affect the apoptotic cascade has yet to be determined. The aim of the present work was to test the involvement of mitochondria in

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Ann. N.Y. Acad. Sci. 1010: 167–170 (2003). © 2003 New York Academy of Sciences.  
doi: 10.1196/annals.1299.028

**TABLE 1. Apoptotic effects of benzo(a)pyrene (72h) in F258 rat liver epithelial cell line**

Cell Treatment	DNA Fragmentation Detected by Hoechst 33342 Staining of Cells (% control population)	Caspase-3-like Activity (% control population)
B(a)P (50 nM)	274.0 ± 1.7%	692.2 ± 69.9%
B(a)P + $\alpha$ -Naphthoflavone (10 $\mu$ M)	118.3 ± 3.4% <sup>a</sup>	85.6 ± 0.1% <sup>a</sup>
B(a)P + Cariporide (30 $\mu$ M)	181.2 ± 2.7% <sup>a</sup>	276.6 ± 21.7% <sup>a</sup>
B(a)P + Bongkreic acid (10 $\mu$ M)	128.9 ± 2.8% <sup>a</sup>	378.2 ± 26.2% <sup>a</sup>
B(a)P + Pifithrin $\alpha$ (10 $\mu$ M)	121.1 ± 2.1% <sup>a</sup>	79.6 ± 0.1% <sup>a</sup>

Results were quoted as mean  $\pm$  SEM of three independent experiments. They were expressed as percentage of effects compared to values obtained from control, untreated cells. Inhibitor, B(a)P-treated cells versus control, B(a)P-treated cells, <sup>a</sup> $P < .05$  (ANOVA followed by Student-Newman-Keuls test).

the apoptotic cascade triggered by B(a)P and to determine the role of  $pH_i$  changes and p53 relative to mitochondria.

## MATERIAL AND METHODS

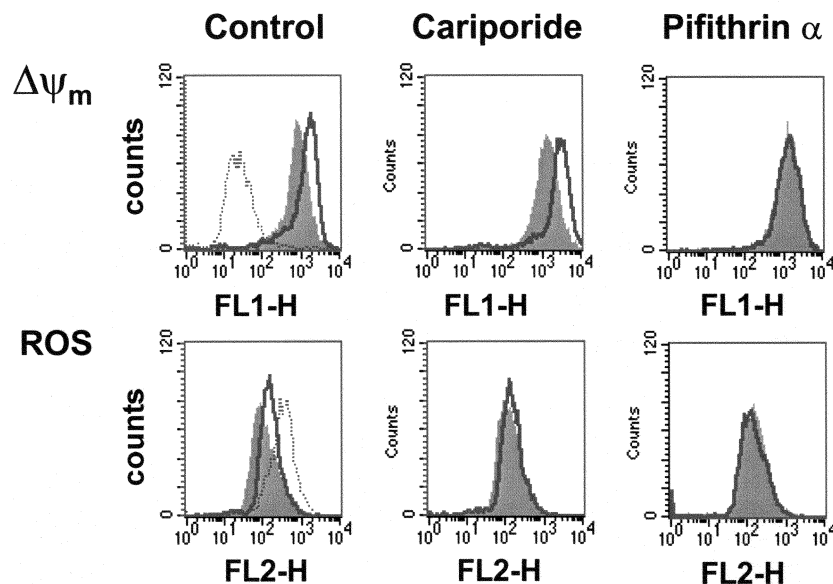
The F258 rat liver epithelial cell line, cultured in Williams' medium E supplemented with 10% fetal calf serum at 37°C under a 5% CO<sub>2</sub> atmosphere, were treated during the exponential phase with 50 nM B(a)P and/or the different inhibitors tested (applied to cells 2 h prior to PAH exposure) for various treatment times.

Microscopical detection of apoptosis was performed in both floating and adherent cells, using Hoechst 33342 (0.5  $\mu$ g/mL) labeling. Caspase activity was measured in cell lysates using the fluorogenic substrate DEVD-AMC.

Mitochondrial potential and ROS production were measured by flow cytometry using DiOC<sub>6</sub>(3) (50 nM) and dihydroethidium (DHE; 5  $\mu$ M), respectively.

## RESULTS AND DISCUSSION

Results quoted in TABLE 1 show that treatment of F258 cells by B(a)P (50 nM, 72 h) led to a significant apoptotic effect (as detected by Hoechst 33342 staining and caspase-3-like activity) compared to untreated counterparts. Using  $\alpha$ -naphthoflavone (10  $\mu$ M; a CYP1A1 inhibitor) and cariporide (30  $\mu$ M; an inhibitor of Na<sup>+</sup>/H<sup>+</sup> exchange which has been shown to inhibit PAH-induced  $pH_i$  change<sup>5</sup>), we demonstrated the involvement of B(a)P metabolism and associated  $pH_i$  changes in the apoptotic cascade elicited by B(a)P. Furthermore, a role for mitochondria and the tumor suppressor p53 was suggested since B(a)P-induced apoptosis was markedly inhibited by bongkreic acid (10  $\mu$ M) and pifithrin  $\alpha$  (10  $\mu$ M), respectively. In order to gain more insight into a putative effect of B(a)P on mitochondrial function, we decided to measure mitochondrial membrane potential ( $\Delta\Psi_m$ ) using DiOC<sub>6</sub>(3) staining of cells. As illustrated in FIGURE 1, a mitochondrial hyperpolarization was



**FIGURE 1.** Effects of B(a)P (50 nM, 48 h) on mitochondrial membrane potential and ROS production in F258 cells. Mitochondrial membrane potential ( $\Delta\Psi_m$ ) and ROS production were measured using DiOC<sub>6</sub>(3) and DHE staining of the cells, respectively. Illustrated histograms were representative of three independent experiments. (*Filled, grey peak*) Control, untreated cells; (*open, black peak*) B(a)P-treated cells; (*open, dotted peak*) positive control cells (i.e., in the presence of FCCP [50  $\mu$ M] and menadione [100  $\mu$ M] when DiOC<sub>6</sub>(3) and DHE were used, respectively).

detected following a 48-h treatment, in contrast to the well described depolarization observed upon FCCP application. We next tested the effects of B(a)P upon ROS production. FIGURE 1 shows that B(a)P induced a marked production of ROS in F258 cells, as pointed out by a rightward shift of the fluorescent peak, similar to that observed with menadione, a known pro-oxidant molecule. This production was found to be inhibited by bongkreic acid (not shown). In order to test the involvement of p53 and of the previously observed B(a)P-induced alkalinization in the changes described above, we evaluated the effects of pifithrin  $\alpha$  (10  $\mu$ M) and cariporide (30  $\mu$ M). Our data show that whereas pifithrin  $\alpha$  prevented both hyperpolarization and ROS production, cariporide was effective only upon ROS production (FIG. 1). Altogether, our results indicate that B(a)P-induced apoptosis might rely upon a p53-dependent and a pH-sensitive mitochondrial dysfunction.

#### ACKNOWLEDGMENTS

This work was supported by grants from the Institut National de Recherche et de Sécurité (INRS) and the Ministère de l'Aménagement du Territoire et de l'Environnement.

## REFERENCES

1. LEI, W., R. YU, S. MANDLEKAR & A.-N.T. KONG. 1998. Induction of apoptosis and activation of interleukin 1 $\beta$ -converting enzyme/Ced-3 protease (caspase-3) and cJun NH<sub>2</sub>-terminal kinase 1 by benzo(a)pyrene. *Cancer Res.* **58**: 2102–2106.
2. KWON, Y.-W., S. UEDA, M. UENO, *et al.* 2002. Mechanism of p53-dependent apoptosis induced by 3-methylcholanthrene. Involvement of p53 phosphorylation and p38 MAPK. *J. Biol. Chem.* **277**: 1837–1844.
3. FLEURY, C., B. MIGNOTTE & J.L. VAYSSIÈRE. 2002. Mitochondrial reactive oxygen species in cell death signaling. *Biochimie* **84**: 131–141.
4. PERVAIZ, S. & M.-V. CLÉMENT. 2002. A permissive apoptotic environment: Function of a decrease in intracellular superoxide anion and cytosolic acidification. *Biochem. Biophys. Res. Commun.* **290**: 1145–1150.
5. HUC, L., L. SPARFEL, A. GUILLOUZO, *et al.* 2002. Apoptosis-related pH<sub>i</sub> changes in rat liver cells treated with benzo(a)pyrene. *Pharmacologist* **44**(suppl. 1): A124 (abstract).