Bone Marrow Transplantation Reveals the in Vivo Expression of the Mitochondrial Uncoupling Protein 2 in Immune and Nonimmune Cells during Inflammation*

Received for publication, June 30, 2003, and in revised form, July 25, 2003 Published, JBC Papers in Press, August 7, 2003, DOI 10.1074/jbc.M306951200

Marie-Clotilde Alves-Guerraz, Sophie Rousset, Claire Pecqueur, Ziad Mallat, Julie Blanc, Alain Tedgui, Frederic Bouillaud, Anne-Marie Cassard-Doulcier, Daniel Ricquier, and Bruno Miroux

From the ‡CNRS UPR 9078, Faculté de Médecine Necker-Enfants Malades, 75730 Paris Cedex 15, France and §INSERM U541, Hôpital Lariboisière, 75475 Paris Cedex 10, France

The mitochondrial uncoupling protein 2 (UCP2) is expressed in spleen, lung, intestine, white adipose tissue, and immune cells. Bone marrow transplantation in mice was used to assess the contribution of immune cells to the expression of UCP2 in basal condition and during inflammation. Immune cells accounted for the total amount of UCP2 expression in the spleen, one-third of its expression in the lung, and did not participate in its expression in the intestine. LPS injection stimulated UCP2 expression in lung, spleen, and intestine in both immune and non-immune cells. Successive injections of LPS and dexamethasone or N-acetyl-cysteine prevented the induction of UCP2 in all three tissues, suggesting that oxygen free radical generation plays a role in UCP2 regulation. Finally, both previous studies and our data show that there is down-regulation of UCP2 in immune cells during their activation in the early stages of the LPS response followed by an up-regulation in UCP2 during the later stages to protect all cells against oxidative stress.

UCP2 belongs to a newly discovered subgroup of mitochondrial carriers proteins related to the well known UCP1 from brown adipose tissue (for review, see Ref. 1). Unlike UCP1, UCP2 and its related family member UCP3 do not seem to be involved in cold-adapted thermogenesis. Studies on Ucp2-/- mice revealed two intriguing phenotypes (for review, see Ref. 2). Zhang et al. (3) found that Ucp2-/- mice exhibit higher serum insulin and lower blood glucose levels compared with wild-type mice. Arsenijevic et al. (4, 6, 7) showed that oxygen free radical generation plays a role in UCP2 regulation. Finally, these results suggest that UCP2 acts as a mild uncoupler, controlling both ATP synthesis as well as the production of ROS (4, 6, 7). However, conflicting data have been obtained regarding the respiratory coupling state of Ucp2-/- and Ucp3-/- mice mitochondria (8–12). Although the uncoupling activity of all UCPs has been established in vitro in proteoliposomes (13–15) and yeast or mammalian mitochondria (16, 17), the in vivo activity of UCP2 and UCP3 is still a matter of debate.

Another approach to understanding the physiological roles of UCP2 has been to study the expression of the protein in wild-type mice. The detection of UCP2 protein is difficult for two main reasons. First, UCP2 is at least 160-fold less abundant in spleen mitochondria than UCP1 in brown adipose tissue. Second, most of the anti-peptide antibodies cross-react with other mitochondrial carriers and, therefore, are misleading. Nevertheless, with the help of the Ucp2-/- mice as negative controls, a highly sensitive anti-UCP2 polyclonal antibody suitable for in vivo detection of UCP2 has been characterized. UCP2 was found to be expressed in spleen, lung, intestine, and, at lower levels, in white adipose tissue (18).

Taking as given the immunologic phenotype of Ucp2-/- mice (4), the induction of the protein after LPS treatment (18), and the presence of immune cells in almost all organs where UCP2 protein was found (18), we set out to determine the precise contribution of immune cells in the expression of UCP2. In the absence of antibodies suitable for in situ detection of UCP2, bone marrow transplantation between Ucp2-/- and Ucp2+/- mice was performed. Levels of UCP2 in all groups of mice were assessed at basal conditions after LPS treatment. To provoke liver injury, mice were also fed an atherogenic diet. Finally, we investigated the effects of N-acetyl-cysteine and dexamethasone on the expression of UCP2 in the LPS model.

MATERIALS AND METHODS

Animals and Treatments—Studies on mice were performed in agreement with the institutional CNRS guidelines defined by the European Community guiding principles and by the French decree No. 87/848 of October 19, 1987. Authorization to perform animal experiments was...
given by the French Ministry of Agriculture, Fisheries and Food (permit A92580 was issued February 2, 1994 and 92–148 was issued May 14, 2002). All mice were 7–10 weeks old. Ucp2–/– mice have been described previously. The mice were transferred onto a C57BL/6J genetic background (99.2%). C57BL/6J mice were purchased from Elevage Janvier (Orleans, France). Mice were injected intraperitoneally with various concentrations of LPS from Escherichia coli serotype 055:B5 (Sigma) and left with free access to food and water. Rectal temperature was measured with a thermocouple probe thermometer (CHY 508BR, Bios- seb, Chaville, France). Mice were killed 14 h after injection. Aerogenous diet was purchased from UAR (Epinay sur Orge, France) and consisted of an A03 diet complete with 15% cocoa butter, 1.25% cholesterol, and 0.5% sodium cholate. Medullar aplasia was induced by 9.5 Gy total body irradiation. Mice were injected intravenously under anesthesia with bone marrow cells (1.2 × 10^6) extracted from the femur and tibia of either Ucp2+/+ or Ucp2–/– mice. The Ucp2–/– mice that received bone marrow from Ucp2–/– mice were named Ucp2–/–tKO, and the Ucp2 mice that received bone marrow from Ucp2–/– were named Ucp2–/–/WT. Macrophage engraftment of hemapoietic tissues after bone marrow transplantation requires one month, whereas the engraftment of Kupffer cells in liver or of resident lung macrophages requires 3–6 months (19, 20). Therefore, transplanted mice were allowed to recover for 4 months to ensure that the engraftment of resident macrophages was close to completion. Transplanted mice were either fed an aerogenous diet for 12 additional weeks or treated with LPS.

Biochemical Methods: Isolation of Mitochondria and Western Blot Analyses—All steps were carried out at 4 °C. Fresh tissues were minced in TES buffer (10 mM Tris, pH 7.5, 1 mM EDTA, 250 mM sucrose) supplemented with the following protease inhibitors: 1 mM benzamidine, 4 μg/ml aprotinin, 1 μg/ml pepstatin, 2 μg/ml leupeptin, 5 μg/ml bestatin, 50 μg/ml soybean trypsin inhibitor, and 0.1 mM phenylmethylsulphonyl fluoride. Minced tissue was carefully disrupted in a Dounce homogenizer. Unbroken cells and nuclei were removed by two successive centrifugations of the homogenate at 750 × g for 10 min. Mitochondria were collected after centrifugation of the supernatant at 10,000 × g for 20 min, and protein content was assayed using a bicinchoninic acid kit (Sigma). The anti-UCP2 antibody (hUCP2 605) and the Western blotting conditions have been described previously (18). Anti-cytochrome c oxidase subunit I (COX I), mono-clonal antibody (1D6), and anti-mitochondrial porin monoclonal antibody were purchased from Molecular Probes (Leiden, The Netherlands) and used at 0.5 μg/ml. Direct recording of the chemiluminescence was performed with the charge-coupled device camera of the GeneGnome instrument, and quantification was achieved using GeneSnap software (Syngene, Ozyme, Saint Quentin en Yvelines, France).

Statistical Analysis—Data are expressed as mean ± S.E. Comparisons between groups were made using a one-way analysis of variance. In the figures, the following correspondences may be found: *, p ≤ 0.05; **, p ≤ 0.01; and ***, p ≤ 0.001. p ≥ 0.05 was considered as statistically significant.

RESULTS

LPS Serotype 055:B5 Induces UCP2 in Multiple Organs—Fig. 1 shows the induction of UCP2 protein 14 h after LPS injection. In contrast to the LPS serotype 0111:B4 used in our previous study (18), the LPS serotype 055:B5 increased UCP2 not only in lung but also in spleen and duodenum (Fig. 1A). At an LPS concentration of 5 mg/kg, UCP2 levels increased 2.7-fold in spleen (p ≤ 0.001). UCP2 levels in the lung and duode-num were increased 2.8- and 2.3-fold, respectively, at an LPS concentration of 10 mg/kg; however, these levels of expression were consistently less than those seen in the spleen (Fig. 1B), which is the predominant organ of UCP2 expression in the conditions examined. Given the importance of the liver in the metabolic response to endotoxin and previous results obtained by Faggioni et al. (22) and Cortez-Pinto et al. (23), we examined the induction of UCP2 in liver by LPS treatment. At a high concentration of this LPS serotype (10 mg/kg), UCP2 increased to a hardly detectable level by our antibody and reached 25% of the basal level of UCP2 in lung (Fig. 2A). The protein band detected below UCP2 is still present in liver mitochondria from Ucp2–/– (Fig. 2B, lane 4) and is, therefore, not UCP2.

Bone Marrow Transplantation Reveals the Contribution of Immune Cells to UCP2 Expression—Expression of UCP2 mRNA in liver has been described in mice fed a fish oil diet (24), LPS-treated mice (22), and genetically deficient ob/ob mice (25–27). In these animal models, liver inflammation can occur, and it is possible, therefore, that the expression of UCP2 observed is due to resident or infiltrating macrophages. To test this hypothesis, bone marrow transplantation was performed. Ucp2+/+ mice, Ucp2–/– mice, Ucp2+/–/tQT-transplanted mice, and Ucp2+/–/tKO-transplanted mice were fed an aerogenous diet or were treated with LPS. After LPS treatment (10 mg/kg), UCP2 protein was induced in liver from Ucp2+/– and Ucp2+/–/tKO mice (Fig. 2A), demonstrating that LPS induced UCP2 in hepatocytes. After 6 weeks of an aerogenous diet containing cholate, the formation of atherosclerotic plaques in both the Ucp2–/– and Ucp2+/– groups of mice was observed (Fig. 2B). Consistent with our previous study on transplanted LDL R–/– mice fed a cholate-free aerogenous diet (5), the mean size of the atherosclerotic plaques was increased four times in Ucp2–/– mice compared with Ucp2+/– (Fig. 2B; p = 0.0011). In contrast to the LPS model of inflammation, the aerogenous diet induced UCP2 protein in liver mitochondria from Ucp2+/– and Ucp2+/–/tQT mice but not in liver mitochondria from Ucp2+/–/tKO mice.
Regulation of Uncoupling Protein 2 during Inflammation

FIG. 2. Induction of UCP2 in liver mitochondria upon LPS treatment or atherogenic diet. Ucp2<sup>+/+</sup> mice were irradiated and transplanted with bone marrow from Ucp<sup>−/−</sup> littermate mice. Ucp2<sup>−/−</sup> mice were transplanted with bone marrow from Ucp<sup>−/−</sup> littermate mice. Four months after transplantation, Ucp2<sup>+/−</sup> mice, Ucp2<sup>−/−</sup> mice, Ucp2<sup>+/−</sup>tWT-transplanted mice, and Ucp2<sup>−/−</sup>tKO-transplanted mice were subjected to LPS injection or to an atherogenic diet. A, Western blot analysis of UCP2 induction in liver mitochondria after 10 mg/kg LPS or NaCl injection. B, effect of the atherogenic diet on Ucp2<sup>−/−</sup> and Ucp2<sup>+/−</sup> mice. Serial sections of the aortic sinus were assayed for lipid deposition with oil-red. The arrow indicates the atherosclerotic plaques (L, lumen). Lesion sizes were also measured on both groups of mice. C, Western blot analysis of the expression of UCP2 in liver after the atherogenic diet. COX I antibody was used to normalize the amount of mitochondrial protein loaded. D, representative examples of MOMA-2 immunostaining in red of frozen liver sections from Ucp2<sup>+/−</sup> mice and Ucp2<sup>−/−</sup>tWT mice on normal diet and from Ucp2<sup>−/−</sup>tWT after the atherogenic diet.

(Fig. 2C). This result shows that the relatively high level of UCP2 protein (50% of the level of UCP2 in control lung) detected in response to an atherogenic diet is associated with immune cells and not with hepatocytes. To confirm this observation, frozen sections of liver were immunostained with the MOMA-2 macrophage-specific antibody (Fig. 2D). Resident macrophages were present in both Ucp2<sup>+/−</sup> control mice and in Ucp2<sup>+/−</sup>tWT-transplanted mice, showing that 4 months after bone marrow transplantation, repopulation of the liver by immune cells has occurred. As revealed by the strong MOMA-2 staining, the atherogenic diet in the presence of cholate triggered a massive infiltration of macrophages in the liver of Ucp2<sup>−/−</sup>tWT mice (Fig. 2D).

In spleen, expression of UCP2 almost disappeared in the Ucp2<sup>−/−</sup>tKO mice (Fig. 3A), showing that UCP2 protein is more than 90% associated with immune cells in this organ (Fig. 3D). In contrast, expression of UCP2 in duodenum disappeared in Ucp2<sup>−/−</sup>tWT mice, demonstrating the expression of UCP2 within intestine cells only (Fig. 3B). Lung exhibited an intermediary phenotype. A significant amount of UCP2 protein is present in the lung of Ucp2<sup>−/−</sup>tWT (Fig. 3C), corresponding to 30% of the signal found in untransplanted mice. To verify that the transplantation was completed, wild-type mice were also transplanted with wild-type bone marrow (Ucp2<sup>+/−</sup>tWT), and the level of UCP2 in spleen was measured in all groups of mice. As shown in Fig. 3D, the levels of UCP2 protein in the spleen of Ucp2<sup>−/−</sup>tWT and Ucp2<sup>−/−</sup>tWT mice were comparable to the level of UCP2 in the spleen of untransplanted wild-type mice.

LPS injection stimulated UCP2 protein in spleen of Ucp2<sup>−/−</sup>tKO mice only (data not shown). However, in the lung, stimulation of UCP2 expression occurred in both groups of mice (Fig. 4), showing that 14 h after injection, both immune and non-immune cells up-regulate UCP2. In intestine, a weak UCP2 protein signal appeared in the Ucp2<sup>−/−</sup>tKO mice treated with LPS (data not shown), indicating that, in addition to the induction of UCP2 by intestine cells, a small proportion of immune cells contributed to UCP2 induction by LPS.

Effects of N-Acetyl-cysteine and Dexamethasone after LPS Injection—To confirm that UCP2 responds to the septic shock induced by LPS, mice were first injected intraperitoneally with LPS (5 mg/kg) and 1 h later, with either N-acetyl-cysteine (150 mg/kg) or dexamethasone (1 mg/kg). As expected, the high concentration of LPS induced a severe hypothermia, with body temperature decreasing to 35 °C (Fig. 5A). Both N-acetyl-cysteine and dexamethasone significantly restored the body temperature (p ≤ 0.01 or 0.001) and prevented UCP2 induction in spleen, lung, and duodenum (Fig. 5, B and C).

DISCUSSION

Bone Marrow Transplantation Reveals New Expression Pattern of UCP2—In spleen, UCP2 expression is thoroughly restricted to immune cells, which confirms that UCP2 is expressed in macrophages and lymphocytes as proposed previously (4, 11). However, immune cells do not contribute to the UCP2 protein detected in intestine. The lung exhibits an intermediary phenotype. In liver, expression of UCP2 can be ascribed to either hepatocytes or to resident and infiltrating immune cells, depending on the inflammatory model. The pres-
ence of cholate in the atherogenic diet, which causes a chronic inflammation of the liver, triggers macrophage infiltration, whereas LPS injection, which induces a severe septic shock for a short period of time, is probably not sufficient to allow a massive infiltration of immune cells. All together, these data showed that immune cells are a dominant site for UCP2 expression, which should be taken into account when measuring UCP2 expression in vivo.

Anti-inflammatory Drugs Confirm the Involvement of UCP2 during Inflammation—Dexamethasone has been shown to significantly reduce neutrophil infiltration in bronchoalveolar lavage fluid and, consequently, the oxidative burst activity in the lung of LPS-treated mice (28). It also inhibits, via the NFκB regulation pathway, the production of cytokines and chemokines such as TNFα, interleukine-1α and -1β, and macrophage inhibitor protein-1α (28, 29). In contrast, NAC exerts a weaker effect on cytokine regulation (28, 30), but it attenuates several

Fig. 3. Expression pattern of UCP2 after bone marrow transplantation. Ucp2 +/− mice were irradiated and transplanted with bone marrow from Ucp2−/− mice (Ucp2−/−tKO) or from Ucp2−/− mice (Ucp2−/−tWT), whereas Ucp2−/− mice were transplanted with bone marrow from Ucp2+/− mice (Ucp2−/+tWT). Four months after transplantation, mice were killed and expression of UCP2 was analyzed by Western blot in mitochondria from spleen (A), duodenum (B), and lung (C). COX I antibody was used to normalize the amount of mitochondrial protein loaded. D, expression of UCP2 in the spleen of all groups of transplanted mice compared with untransplanted mice. Mitochondrial porin antibody was used to estimate the amount of mitochondrial proteins.

Fig. 4. LPS induction of UCP2 in the lung of transplanted mice. Ucp2−/− tKO mice and Ucp2−/− tWT mice were intraperitoneally injected either with LPS (10 mg/kg) or with NaCl as control. Lung mitochondria were prepared, and the expression of UCP2 was measured by Western blot in all groups of mice. A, immunoblot decorated with the hUCP2605 and the COX I antibody to normalize the amount of mitochondrial protein loaded. B, quantification of the induction of UCP2 by LPS in nonimmune cells (Ucp2−/− tKO mice) and in immune cells (Ucp2−/− tWT mice). NaCl-injected mice were used as references.

Fig. 5. N-Acetyl-cysteine and dexamethasone prevent UCP2 induction by LPS. Mice (five animals/group) were injected with LPS (5 mg/kg) and 1 h later with NAC (150 mg/kg) or dexamethasone (DEX) (1 mg/kg). Mitochondria from lung, spleen, and duodenum were prepared 14 h after LPS injection. A, body temperature of mice. B, Western blot analysis of UCP2 expression in lung mitochondria from LPS-, LPS + NAC-, or LPS + DEX-treated mice. C, induction in the percentage of UCP2 in spleen, lung, and duodenum after LPS treatment. NaCl-injected mice were used as references.
pathophysiologic changes in lung tissue, as reported by Bernhard et al. (31) in a sheep model of adult respiratory distress syndrome. The inhibiting effects of dexamethasone and NAC on UCP2 induction by LPS suggest that free radicals may directly regulate the expression of UCP2 either at the transcriptional level as described by Pecqueur et al. (18) or at the translational level. In addition, the possibility that UCP2 regulation is determined by cytokine levels cannot be excluded. Systemic LPS injection in mice triggers an increase in blood TNFα level in less than 2 h, which is followed by bronchopulmonary hyperactivity and an accumulation of neutrophils in the microvasculature of the lung (29). UCP2 induction occurs just after the peak of the cytokine levels. However, Menon et al. (32) reported that TNFα is not required for the up-regulation of UCP2 mRNA levels observed in the genetically obese ob/ob mice, and Nakatani et al. (33) showed that PPARα activators up-regulated liver Ucp2 mRNA by means of a TNFα-independent pathway.

**Acknowledgments** — We thank Nathan Hellman for critical reading of the manuscript and Edwige Declercq for animal care.

**REFERENCES**

1. Ricquier, D., and Bouillaud, F. (2000) Biochem. J. 345, Pt 2, 161–179
2. Alves-Guerra, M. C., Pecqueur, C., Shaw, A., Couplan, E., Gonzalez-Barrero, M. M., Ricquier, D., Bouillaud, F., and Miroux, B. (2002) in Cell and Molecular Responses to Stress: Sensing, Signaling and Cell Adaptation (Storey, K. B., and Storey, J. M., eds), Vol. 3, pp. 257–268, Elsevier Press, Amsterdam, The Netherlands
3. Zhang C. Y., Baffy G., Perret P., Krauss S., Peroni O., Gumeniuc D., Hagen T., Vidal-Puig A., Boss O., Kim Y. B., Zheng X. X., Wheeler M. B., Shulman G. I., Chan C. B., and Lowell B. B. (2001) Cell 105, 745–755
4. Arsenijevic D., Onuma H., Pecqueur C., Rainhault S., Manning B. S., Miroux B., Couplan E., Alves-Guerra M. C., Goubern M., Surwit R., Bouillaud F., Richard D., Collins S., and Ricquier, D. (2000) Nat. Genet. 24, 455–469
5. Blanc J., Alves-Guerra M. C., Espósito B., Rousset S., Gourdy P., Ricquier D., Tedgui A., Miroux B., and Mallat Z. (2003) Circulation 107, 388–390
6. Scarchera M., V. P. (1996) Q. Rev. Biochem. 29, 169–202
7. Negre-Salvayre A., Hirtz C., Carrera G., Cazenave H., Troly M., Salvayre R., Penicaud L., and Castella L. (1997) PASEB J. 11, 809–815
8. Cline G. W., Vidal-Puig A. J., Dufour S., Cadman K. S., Lowell B. B., and Shulman G. I. (2001) J. Biol. Chem. 276, 29240–29244
9. Couplan E., del Mar Gonzalez-Barrero M., Alves-Guerra M. C., Ricquier D., Goubern M., and Bouillaud F. (2002) J. Biol. Chem. 277, 26268–26275
10. Echiny K. S., Roussel D., St-Pierre J., Jekabsons M. B., Cadenas S., Stuart J. A., Harper J. A., Roebeck S. J., Morrison A., Pickering S., Clapham J. C., and Brand, M. D. (2002) Nature 415, 96–99
11. Krauss S., Zhang C. Y., and Lowell, B. B. (2002) Proc. Natl. Acad. Sci. U. S. A. 99, 119–122
12. Vidal-Puig A. J., Goubern M., Zhang C. Y., Hagen T., Boss O., Ido Y., Sanczakpanik A., Wade J., Mootha V., Cortright R., Muzis D. M., and Lowell B. B. (2000) J. Biol. Chem. 225, 16258–16266
13. Jaburek, M., and Garlid, K. D. (2003) J. Biol. Chem. 278, 53852–53851
14. Echiny K. S., Winkler E., Frischmuth K., and Klingenberg, M. (2003) Proc. Natl. Acad. Sci. U. S. A. 98, 1416–1421
15. Jaburek M., Varecha M., Gimeno R. E., Dembski M., Jezek P., Zhang M., Burn P., Tartaglia L. A., and Garlid, K. D. (1999) J. Biol. Chem. 274, 27603–27607
16. Fink, B. D., Hong Y. S., Mathias M. H., Scholz T. D., Dillon J. S., and Sivitz, W. I. (2002) J. Biol. Chem. 277, 3918–3925
17. Ricquier, D., Gonzalez-Barrero, M. C., Baffy G., Perret P., Krauss S., Peroni O., Bouillaud F., and Miroux B. (1999) EMBO J. 18, 5827–5833
18. Pecqueur C., Alves-Guerra M. C., Gelly C., Levi-Meyrueis C., Couplan E., Collins S., Ricquier D., Bouillaud F., and Miroux B. (2001) J. Biol. Chem. 276, 8705–8712
19. Kennedy, D. W., and Abkowitz, J. L. (1997) Blood 90, 886–893
20. Nakata K., Gotoh H., Watanabe J., Utakake T., Komuro I., Yausa K., Watanabe S., Ieki R., Sakamaki H., Akiyama H., Kudo H., Niitoh M., Satoh H., and Shimada, K. (1999) Blood 93, 667–673
21. Mallat, Z., Silvestre, J. S., Le Ricousse-Roussanne, S., Lecomte-Raclet, L., Corbaz, A., Clergue, M., Duriez, M., Barateau, V., Akira, S., Tedgui, A., Tobelem, G., Chvatchko, Y., and Levy, B. I. (2002) Circ. Res. 91, 441–448
22. Faggioni, R., Shigenaga, J., Moser, A., Feingold, K. R., and Grunfeld, C. (1998) Biochem. Biophys. Res. Commun. 244, 75–78
23. Cortez-Pinto, H., Yang, S. Q., Lin, H. Z., Costa, S., Hwang, C. S., Lane, M. D., Bagby, G., and Diehl, A. M. (1998) Biochem. Biophys. Res. Commun. 251, 313–319
24. Tsuboyama-Kasaoka, N., Takahashi, M., Kim, H., and Ezaki, O. (1999) Biochem. Biophys. Res. Commun. 257, 879–885
25. Chavin, K. D., Yang, S., Lin, H. Z., Chatham, J., Chacko, V. P., Heck, J. B., Walajtys-Rode, E., Rashid, A., Chen, C. H., Huang, C. C., Wu, T. C., Lane, M. D., and Diehl, A. M. (1999) J. Biol. Chem. 274, 5692–5700
26. Rashid, A., Wu, T. C., Huang, C. C., Chen, C. H., Lin, H. Z., Yang, S. Q., Lee, F. Y., and Diehl, A. M. (1999) Hepatology 29, 1131–1138
27. Yang, S., Zhu, H., Li, Y., Lin, H., Gabrielson, K., Trush, M. A., and Diehl, A. M. (2000) Arch. Biochem. Biophys. 376, 259–268
28. Rocksen, D., Lilliehook, B., Larsson, B., Johansson, T., and Bucht, A. (2000) Clin. Exp. Immunol. 122, 249–256
29. Lefort, J., Singer, M., Leduc, D., Renesto, P., Nahori, M. A., Huerec, M., Creminon, C., Chignard, M., and Varpaag, B. B. (1998) J. Immunol. 161, 474–480
30. Gatti, S., Faggioni, R., Echtenacher, B., and Ghezzi, P. (1993) Clin. Exp. Immunol. 91, 456–461
31. Bernard, G. R., Lucht, W. D., Niedermeyer, M. E., Snapper, J. R., Ogletree, M. L., and Brigham, K. L. (1984) J. Clin. Invest. 73, 1772–1784
32. Memon, R. A., Hotamisligil, G. S., Weshbrook, S. M., Uysal, K. T., Faggioni, R., Moser, A. H., Feingold, K. R., and Grunfeld, C. (2000) Biochim. Biophys. Acta 1484, 41–50
33. Nakatani, T., Tsuboyama-Kasaoka, N., Takahashi, M., Miura, S., and Ezaki, O. (2002) J. Biol. Chem. 277, 9562–9569
34. Lee, F. Y., Li, Y., Yang, E. K., Yang, S. Q., Lin, H. Z., Trush, M. A., Dannelsberg, A. J., and Diehl, A. M. (1999) Am. J. Physiol. 276, C386–C394
35. Kizaki, T., Suzuki, K., Hitomi, Y., Taniguchi, N., Saitoh, D., Watanabe, K., Onoe, K., Day, N. K., Good, R. A., and Ohno, H. (2002) Proc. Natl. Acad. Sci. U. S. A. 99, 8392–8397
36. Chen, Z., Gordon, J. R., Zhang, X., and Xiang, J. (2002) Biochem. Biophys. Res. Commun. 290, 66–72
Bone Marrow Transplantation Reveals the in Vivo Expression of the Mitochondrial Uncoupling Protein 2 in Immune and Nonimmune Cells during Inflammation
Marie-Clotilde Alves-Guerra, Sophie Rousset, Claire Pecqueur, Ziad Mallat, Julie Blanc, Alain Tedgui, Fredéric Bouillaud, Anne-Marie Cassard-Doulcier, Daniel Ricquier and Bruno Miroux

J. Biol. Chem. 2003, 278:42307-42312.
doi: 10.1074/jbc.M306951200 originally published online August 7, 2003

Access the most updated version of this article at doi: 10.1074/jbc.M306951200

Alerts:
- When this article is cited
- When a correction for this article is posted

Click here to choose from all of JBC's e-mail alerts

This article cites 36 references, 19 of which can be accessed free at http://www.jbc.org/content/278/43/42307.full.html#ref-list-1