Volume 238, number 2, 353–356 FEB 06387 October 1988

Inhibition of adriamycin-promoted microsomal lipid peroxidation by β-carotene, α-tocopherol and retinol at high and low oxygen partial pressures

Glenn F. Vile and Christine C. Winterbourn

Department of Pathology, Christchurch School of Medicine, Christchurch Hospital, Christchurch, New Zealand

Received 19 August 1988

Iron-dependent peroxidation of rat liver microsomes, enhanced by adriamycin, was measured in the presence of increasing concentrations of α-tocopherol, β-carotene and retinol at low and high pO_2. β-Carotene and α-tocopherol inhibited lipid peroxidation by more than 60% when present at concentrations greater than 50 nmol/mg microsomal protein at both high and low pO_2. Retinol inhibited peroxidation by 39% at concentrations greater than 100 nmol/mg microsomal protein. This maximal level of inhibition by retinol was unaltered by pO_2. However, β-carotene was more effective than α-tocopherol or retinol at a pO_2 of 4 mmHg, whereas α-tocopherol was more effective under aerobic conditions. Since adriamycin-dependent lipid peroxidation is maximal at low pO_2, β-carotene may play a role in protecting against this process.

Lipid peroxidation; Microsome; Adriamycin; β-Carotene; α-Tocopherol

1. INTRODUCTION

The peroxidation of lipids has been proposed as a mechanism by which redox-active xenobiotics, including the anticancer drug adriamycin, cause cell damage [1–3]. Adriamycin is reduced by cellular enzymes and enhances lipid peroxidation in a variety of systems [3–5], suggesting that its dose-limiting cardiotoxicity could be a result of myocyte membrane peroxidation [4–6]. Recently, we have shown that adriamycin-dependent peroxidation of microsomes is 4–5-fold greater at low O_2 partial pressures than in air [7]. Thus, lipid peroxidation in vivo should be favoured by low O_2 partial pressures, such as exist in active muscle tissue [8].

Lipid peroxidation is inhibited by chain-breaking antioxidants. α-Tocopherol, the best known of these, is considered to be the major physiological inhibitor of lipid peroxidation [9]. Several in vitro studies of adriamycin-dependent peroxidation have shown inhibition by α-tocopherol [10,11] although the effects of deficiency or supplementation have been equivocal [12–15]. The ability of α-tocopherol to inhibit lipid peroxidation declines with decreasing pO_2 [16]. In contrast, Burton and Ingold [16] have shown that β-carotene becomes more efficient at inhibiting peroxidation of linoleic acid as the pO_2 decreases. This suggests that β-carotene and like compounds may provide better protection than α-tocopherol against adriamycin-induced lipid peroxidation.

To test this proposal, we have compared the abilities of α-tocopherol, β-carotene and retinol to inhibit adriamycin-dependent microsomal lipid peroxidation in air and at low pO_2.

Correspondence address: G. Vile, Department of Pathology, Christchurch School of Medicine, Christchurch Hospital, Christchurch, New Zealand

2. MATERIALS AND METHODS

Biochemicals were from Sigma (St. Louis, MO) except for

Published by Elsevier Science Publishers B.V. (Biomedical Division)
00145793/88/$3.50

adriamycin (from Farmitalia, Carlo Erba, Italy). Liver microsomes were prepared from Wistar rats according to Ernster et al. [17], and stored in 10 mM phosphate buffer (pH 7.4), at −100°C. Microsomal protein was measured by the method of Lowry et al. [18]. β-Carotene and α-tocopherol, at the required concentrations, were incorporated into the microsomal membrane by pelleting the microsomes at 105000 × g and gently homogenising the pellet with antioxidant solubilised in 10 μl chloroform, using a Potter-Elvehjem homogeniser. Once mixing was complete the microsomes were resuspended in buffer. When β-carotene-enriched microsomes were ultracentrifuged, all the β-carotene spun down with the microsomes, demonstrating that it was incorporated into the microsomal membrane. Cytochrome P450 reductase activity of the antioxidant-enriched microsomes was standardized such that 50 μl of each preparation, in 1 ml buffer with 100 μM NADPH, reduced cytochrome *c* at a rate of 3 μM/min. Procedures were carried out in acid-washed glassware and buffers were treated with chelex resin (Biorad Lab, CA) to remove adventitious iron.

2.1. *Lipid peroxidation*

Microsomes (0.5 mg protein/ml) were incubated with 100 μM NADPH, 1.0 μM $FeCl_3$ and 30 μM adriamycin for 30 min at 22°C in 10 mM phosphate buffer (pH 7.4). Reactions were performed in 10 ml rubber-stoppered glass tubes in which the pO_2 was manipulated by bubbling solution with O_2-free N_2 and replacing the requisite volume of N_2 with O_2 using a gas-tight syringe. Solutions were continually mixed by rotation. Lipid peroxidation was measured as A_{532} due to the formation of thiobarbituric acid-reactive products as described in [19]. Blanks contained adriamycin and microsomes but no NADPH or iron, and where appropriate, an equivalent amount of β-carotene.

2.2. *β-Carotene bleaching*

Microsomes (0.5 mg), containing 25 μM β-carotene, were incubated with 1.0 μM $FeCl_3$ and 100 μM NADPH in 1 ml phosphate buffer in the presence and absence of adriamycin. β-Carotene bleaching was continuously monitored at 466 nm.

3. RESULTS

In the absence of adriamycin, addition of NADPH and iron to rat liver microsomes caused a small amount of lipid peroxidation that was relatively independent of pO_2 (table 1). As we have shown previously [8], adriamycin enhanced peroxidation less than 2-fold in air, but 4–5-fold at pO_2 values of 4–8 mmHg (table 1).

Both α-tocopherol and β-carotene gave a concentration-dependent inhibition of adriamycin-dependent peroxidation either at pO_2 4 mmHg (fig.1A) or in air (fig.1B). Whereas in air α-tocopherol gave more inhibition than an equivalent concentration of β-carotene, in low air β-carotene was a more efficient inhibitor. Maximum inhibition was achieved with >50 nmol of either antioxidant/mg microsomal protein, and the two together gave no greater inhibition than either one alone. The O_2 dependence curves in fig.2 show

Table 1

Effect of pO_2 on adriamycin-dependent peroxidation of microsomal lipids

pO_2 (mmHg)	A_{532}	
	−	+ adriamycin
0	0.09	0.11
4	0.14	0.73
8	0.15	0.70
80	0.14	0.28
160	0.14	0.27

Microsomes were incubated with or without 30 μM adriamycin, NADPH and 1 μM $FeCl_3$ as described in section 2. Each result is the mean of 4 experiments that agreed within 10%

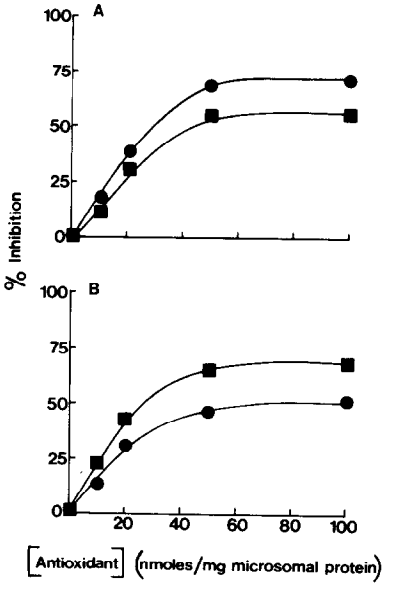

Fig.1. Effect of β-carotene and α-tocopherol concentration on adriamycin-enhanced microsomal lipid peroxidation at (A) pO_2 = 4 mmHg and (B) pO_2 = 162 mmHg. Microsomes were incubated with adriamycin, NADPH, $FeCl_3$ and β-carotene (●) or α-tocopherol (■) at the concentrations shown. Blanks due to antioxidant, anthracycline and microsomes incubated without NADPH were subtracted and percent inhibition was calculated. Each point is the mean for two sets of duplicates and the SD falls within each symbol size.

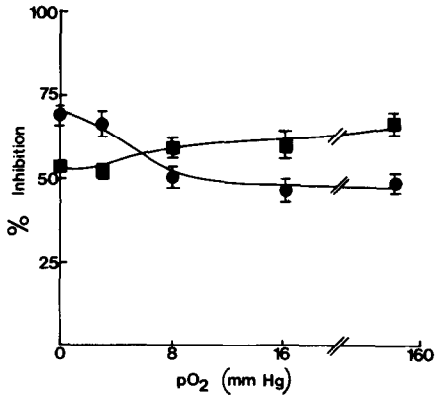

Fig.2. Inhibition of adriamycin-dependent microsomal lipid peroxidation by (●) 50 nmol/mg β-carotene microsomal protein and (■) 50 nmol α-tocopherol/mg microsomal protein under increasing pO_2. Microsomes were incubated with adriamycin, $FeCl_3$ and NADPH. Blanks due to antioxidant, anthracycline and microsomes incubated without NADPH were subtracted and percent inhibition was calculated. Each point is the mean for two sets of duplicates.

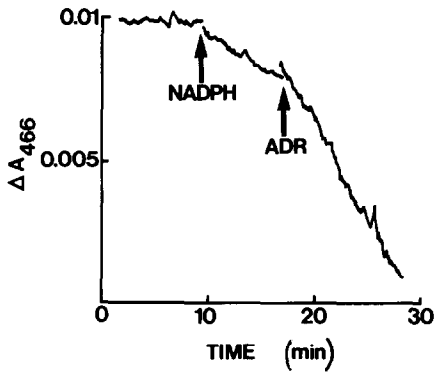

Fig.3. Effect of adriamycin (ADR) on the bleaching of β-carotene incorporated into microsomal membranes. Incubations were with $FeCl_3$ and 0.5 mg microsomes containing 25 nmol β-carotene, in 1 ml buffer, under aerobic conditions. The spectrophotometer trace shown is representative of 3 experiments.

that β-carotene inhibited more than α-tocopherol only at very low pO_2.

Maximum inhibition by retinol required >100 nmol/mg microsomal protein and was similar at the two O_2 concentrations (table 2).

As evidence that β-carotene was consumed during lipid peroxidation, continuous monitoring of A_{466} showed bleaching of β-carotene-enriched microsomes (fig.3). The rate of bleaching was enhanced 3-fold upon the addition of adriamycin.

Table 2

Effect of retinol on adriamycin-dependent peroxidation of microsomal lipids

[Retinol] (nmol/mg microsomal protein)	% inhibition of lipid peroxidation (A_{532})
20	13
40	23
100	37
100 (pO_2 = 162 mmHg)	39

Microsomes were incubated with NADPH, adriamycin, $FeCl_3$ and retinol at pO_2 = 4 mmHg, except where indicated. A_{532} values were read against a blank containing retinol, of the appropriate concentration, microsomes, and adriamycin, but no NADPH. Percent inhibition was calculated from A_{532} values of the complete system with and wihtout retinol. Each result is the mean of 2 sets of duplicates which agreed within 15%

4. DISCUSSION

This work demonstrates that β-carotene significantly inhibits adriamycin-dependent lipid peroxidation of microsomes in air. It is slightly less efficient than α-tocopherol, but as the pO_2 declines and inhibition by α-tocopherol decreases, there is an increase in inhibition by β-carotene. Retinol also inhibits adriamycin-dependent lipid peroxidation, although the degree of inhibition is similar at the different pO_2 values.

α-Tocopherol inhibits lipid peroxidation by reacting with the lipid hydroperoxy radical [16], thus inhibiting propagation of the chain reaction (reaction 3):

$$LH + R^{\cdot} \longrightarrow L^{\cdot} + RH \quad (1)$$

$$L^{\cdot} + O_2 \longrightarrow LOO^{\cdot} \quad (2)$$

$$LOO^{\cdot} + LH \longrightarrow LOOH + L^{\cdot} \text{ [propagation]} \quad (3)$$

$$LOO^{\cdot} + H \longrightarrow LOOH \text{ [termination]} \quad (4)$$

The chain-breaking action of α-tocopherol is most efficient at high pO_2 and as the pO_2 decreases this mechanism of inhibition becomes less efficient. However, as this happens, antioxidants such as β-carotene and retinol that can compete with O_2 for the lipid radical ($L^{\cdot}$, reaction 2) become better scavengers. Thus, Burton and Ingold [16] have proposed that this class of compound should pro-

vide better protection than α-tocopherol against peroxidation processes occurring at low pO_2.

Since adriamycin-dependent microsomal lipid peroxidation is optimal at low pO_2, their proposal implies that β-carotene should be better than α-tocopherol at inhibiting this process. Our results show that this is indeed the case, although the differences between β-carotene and α-tocopherol are not as great as might be expected from the conclusions of Burton and Ingold. However, in their studies on linoleic acid, the greatest difference in relative efficiencies of β-carotene and α-tocopherol was between air and O_2, and their results at lower pO_2 are comparable to ours.

The observed inhibition of lipid peroxidation by retinol, although not enhanced under low pO_2, was still significant. Retinol is frequently dismissed as an antioxidant, because, compared with β-carotene, it is ineffective at scavenging O_2 [20]. However, this study has demonstrated that retinol does have antioxidant properties.

Normal levels of β-carotene, α-tocopherol and retinol in chick liver are 0.17, 9.7 and 153 nmol/mg for liver tissue, respectively [21]. Supplementation is able to elevate levels of all three 4–7-fold [21]. However, the fact that levels of retinol are comparatively so much higher, and the demonstration of antioxidant activity in this study, suggest that the physiological significance of the antioxidant activity of retinol appears to have been underestimated. Our results provide supporting evidence for the proposed antioxidant role for β-carotene and retinol, and raise the possibility that they could protect against adriamycin-induced cardiotoxicity. Indeed, vitamin A in association with α-tocopherol has been shown to decrease cardiotoxicity of adriamycin in rabbits [22].

Acknowledgements: This work was supported by the New Zealand Medical Research Council and the Cancer Society of New Zealand.

REFERENCES

[1] Sandy, M.S., Moldeus, P., Ross, D. and Smith, M.T. (1986) Biochem. Pharmacol. 35, 3095–3101.
[2] Dillard, C.J., Kunert, C.J. and Tappel, A.L. (1982) Arch. Biochem. Biophys. 216, 204–212.
[3] Goodmand, J. and Hochstein, P. (1977) Biochem. Biophys. Res. Commun. 77, 797–803.
[4] Mimnaugh, E.G., Trush, M.A. and Gram, T.E. (1981) Biochem. Pharmacol. 30, 2797–2804.
[5] Mimnaugh, E.G., Gram, T.E. and Trush, M.A. (1983) J. Pharmacol. Exp. Ther. 226, 806–816.
[6] Myers, C.E., McGuire, W.P., Liss, R.H., Ifrim, I., Grotzinger, K. and Young, R.C. (1977) Science 197, 165–167.
[7] Vile, G.F. and Winterbourn, C.C. (1988) Biochem. Pharmacol., in press.
[8] Coburn, R.F. and Mayers, L.B. (1971) Am. J. Physiol. 220, 66–74.
[9] Burton, G.W., Joyce, A. and Ingold, K.U. (1983) Arch. Biochem. Biophys. 221, 281–290.
[10] Pascoe, G.A. and Reed, D.J. (1986) Arch. Biochem. Biophys. 256, 159–166.
[11] Stuart, M.J., De Alarcon, P.A. and Barvinchak, M.K. (1978) Am. J. Hematol. 5, 297–303.
[12] Sonneveld, P. (1978) Cancer Treat. Rep. 62, 1033–1036.
[13] Wang, Y., Madanat, F.F., Kimball, J.C., Gleiser, C.A., Ali, M.K., Kaufman, M.W. and Van Eys, J. (1980) Cancer Res. 40, 1022–1027.
[14] Breed, J.G.S., Zimmerman, A.N.E., Dormans, J.A.M.A. and Pinedo, H.M. (1980) Cancer Res. 40, 2033–2038.
[15] Van Vlett, J.F., Ferrans, V.J. and Weirich, W.E. (1980) Am. J. Pathol. 99, 13–42.
[16] Burton, G.W. and Ingold, K.U. (1984) Science 224, 569–573.
[17] Ernster, L., Siekevitz, P. and Palade, G.E. (1962) J. Cell. Biol. 15, 541–562.
[18] Lowry, O.H., Rosebrough, N.J., Farr, A.L. and Randall, R.J. (1951) J. Biol. Chem. 193, 265–275.
[19] Winterbourn, C.C., Gutteridge, J.M.C. and Halliwell, B. (1985) J. Free Radical Biol. Med. 1, 43–49.
[20] Machlin, L.J. and Bendich, A. (1987) FASEB J. 1, 441–445.
[21] Mayne, S.T. and Parker, R.S. (1986) Lipids 21, 164–169.
[22] Milei, J., Boveris, A., Llesuy, S., Molina, H.A., Storino, R., Ortega, D. and Milei, S.E. (1986) Am. Heart J. 111, 95–102.