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CUTANEOUS ARTERIOLAR DILATATION ELICITED BY ULTRAVIOLET IRRADIATION*

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ABSTRACT

Arteriolar changes in the skin following monochromatic UV irradiation have been investigated with a photoelectric pulsemeter. Arteriolar dilatation was seen at all wavelengths tested and could be detected as early as 2½ hours after irradiation. Intradermal epinephrine was found to produce marked pallor of UV erythema and arteriolar constriction was confirmed with the pulsemeter.

Recordings indicating arteriolar dilatation were identical with 250 nm and 300 nm erythema, despite well documented qualitative differences in the erythema at these wavelengths.

Exposure of human skin to ultraviolet (UV) radiation results in changes in cutaneous blood vessels producing the characteristic erythema (1). There are obvious differences in the erythema which follows exposure in the region of 250 nm and that which occurs with 300 nm; the 250 nm erythema appears earlier, is pinker, and fades quicker than the 300 nm erythema (2, 3), and Van der Leun (4), after studying skin temperature changes suggested that arteriolar dilatation which occurred with 300 nm was absent at 250 nm. The absence of arteriolar dilatation in UV erythema has also been discussed by Rothman (5) and Johnson *et al.* (6).

In the present study the vascular changes associated with UV erythema have been investigated to try to determine whether it is arteriolar dilatation that occurs in the erythema resulting from different wavelengths. A photoelectric pulsemeter, which is a sensitive indicator of arteriolar changes in the skin (7), was used to obtain pulse recordings from erythema and the effect of I.D. epinephrine on the erythema has been re-investigated.

MATERIALS AND METHODS

UV radiation. The minimal erythema dose (MED) was determined with the prism-grating monochromator described by Cripps and Ramsay (8). Various increments of the MED were then given to determine the lowest dose at which arteriolar changes could be detected. The irradiated area measured 0.4 x 0.4 cm.

Measurement of arteriolar changes. Pulsatile changes in cutaneous blood vessels were measured with the photoelectric pulsemeter (Fig. 1) described in detail elsewhere by Ramsay (9). Arteriolar dilatation is indicated by an increase in pulse height and arteriolar constriction by a decrease. Prior to measuring pulsation from the irradiated area an adjacent area of nonirradiated skin was examined so that each subject acts as his own control. The procedure in each case was to obtain a recording first from the nonirradiated site, set the controls to obtain a measurable pulse and then record from the irradiated site at the same control setting. The pulse height may therefore vary from subject to subject and no attempt should be made to compare recordings between different subjects, without reference to the individual's control. All recordings were taken in a draught free room at an ambient temperature between 23° C and 25° C. The speed of the recording paper was 2.5 mm/sec.

Subjects. Eleven subjects with normal skin and no history of photosensitivity received various doses of UV and the erythema was studied 24 hours after irradiation. In 6 subjects erythema from 250 nm and 300 nm was studied and in the other 5 subjects erythema from selected wavelengths: at 280 nm (1 subject), 290 nm (1 subject), 293 nm (2 subjects), 300 nm (1 subject). Recordings at 250 nm and 300 nm (3 × MED) were made at 2½ and 4 hours in 3 subjects and after 96 and 120 hours in one normal subject. In addition, 5 photosensitive patients were studied, 4 with polymorphic light eruption and 1 with solar urticaria. These patients were investigated to determine whether the arteriolar changes produced by various wavelengths were identical to those in normal sub-

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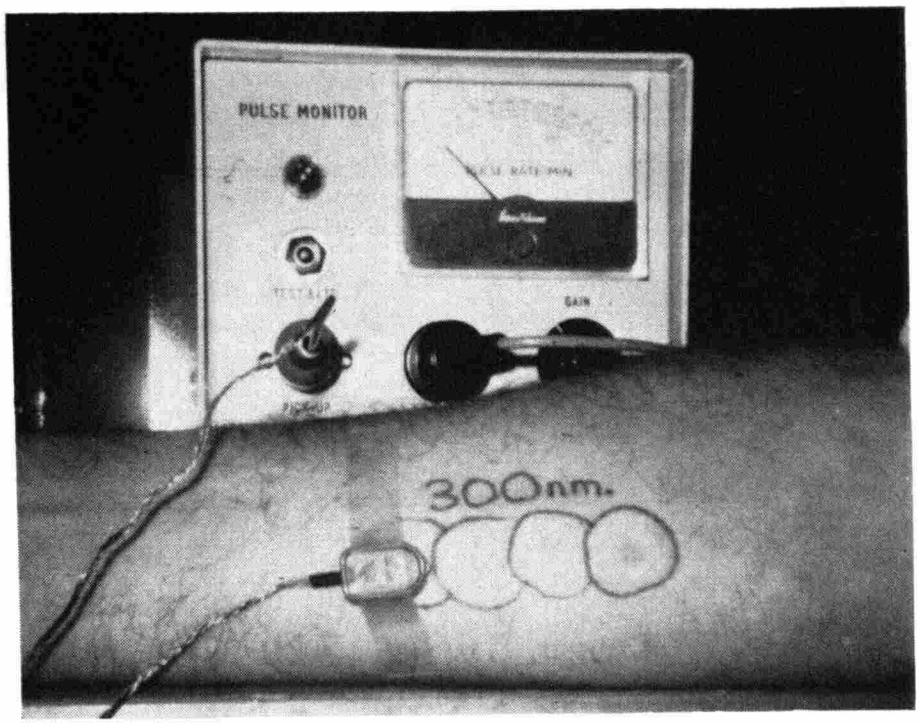

FIG. 1. Method of fixing sensor to the skin for recording from a graded series of erythema. Pulsemeter is shown in the background. For demonstration purposes the forearm was used.

jects. Erythema was studied in all patients at 250 nm, in 2 at 296 nm and in another 2 at 300 nm. Immediate erythema at 250 nm was studied in the patient with solar urticaria (at 250 nm only), but the other 4 patients were studied at 24 hours. All persons received irradiation on the back of the upper trunk except one normal subject who was irradiated at 300 nm on the medial aspect of the upper arm.

Intradermal epinephrine. Erythema resulting from various doses of UV was injected intradermally with 0.05 ml of 1/10,000 epinephrine in isotonic saline. Injections were given into the center of the erythema in 5 normal subjects at 250 nm and 300 nm, 24 hours after irradiation. The sites were examined visually at intervals after injection and in 2 subjects pulsemeter recordings were also obtained.

RESULTS

UV erythema was associated with arteriolar dilatation in all persons and at all wavelengths tested and was present in every case examined at 24 hours but could be detected as early as 2½ hours after irradiation. In addition identical changes were seen in the patient with solar urticaria whose immediate erythema was examined. The irradiated site always showed an increase in pulse height of at least 50% in comparison to the control and in several instances the increase was 100%. Representative tracings are shown in Figure 2.

Our MED was defined as the smallest dose in a graded series which produced erythema that just failed to fill the irradiated area (6, 8). At 250 nm in 3 of the 6 normal subjects arteriolar dilatation could be detected at the MED site while in the other 3 subjects doses up to 2 × MED were necessary. The results at 300 nm were similar, arteriolar dilatation was seen at the MED site in 4 of the 7 normal subjects and no subject required more than 2 × MED. At 280 nm and 290 nm the MED showed increased pulsation in the 2 subjects studied. Arteriolar dilatation at several of these wavelengths could occasionally be detected at doses lower than the MED. Possible reasons for the difference in detection of arteriolar dilatation in terms of dose will be discussed later.

Erythema from 293 nm was studied in 2 normal subjects and sites irradiated with 1.75 × and 2 × the MED respectively showed arteriolar dilatation. Recordings from sites irradiated at lower doses were not performed but the results are included because they are identical to results obtained at other wavelengths.

The MED at 250 nm showed arteriolar dilatation in 4 of the 5 photosensitive patients, the other requiring 1.5 × MED, while at 300 nm both patients examined showed changes at the MED site. At 296 nm arteriolar dilatation was detectable at the MED site in one patient and at 2 × MED in the other.

Recordings with 3 × MED for 250 nm and 300 nm at 96 and 120 hours after irradiation

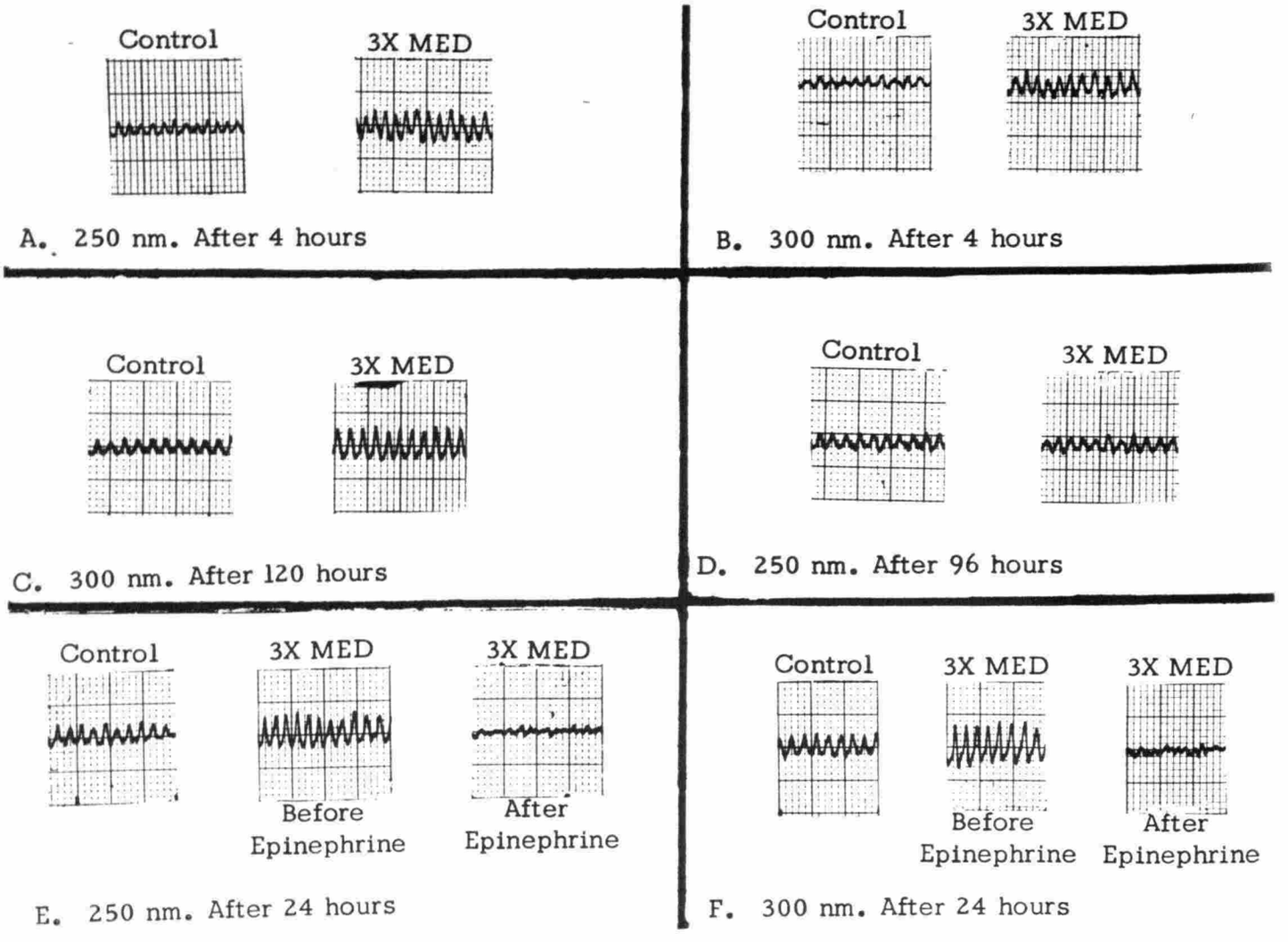

FIG. 2. Pulsemeter recordings from UV erythema and adjacent control sites. Recordings taken at varying times after irradiation at 250 nm and 300 nm. For details see text.

were obtained in one normal subject. The 300 nm erythema was still visible at 120 hours and arteriolar dilatation was still present (Fig. 2C). However, by 96 hours the 250 nm site had returned to normal and no increase in pulsation over the control site could be detected (Fig. 2D).

Effect of I.D. Epinephrine

The MED site was injected in 5 subjects and 4 showed disappearance of the erythema, considerable pallor developed in the other subject, although some erythema was still visible. The sites irradiated with 2 × or 3 × MED at 250 nm and 300 nm showed a marked reduction in the degree of erythema after epinephrine and the occurrence of arteriolar constriction was confirmed by pulse tracings (Fig. 2, E and F). A similar result was obtained on the one occasion when 10 × MED at 300 nm was injected. Erythema reappeared after the pallor from the epinephrine had cleared and its later progress was no different from similar irradiated sites which had not been injected.

DISCUSSION

The validity of the conclusions reached here depends upon the assumption that the cutaneous blood volume pulse, as recorded by the photoelectric pulsemeter, can be used as a measure of the arterial supply of the skin. The instrument detects the amount of blood present in the cutaneous vessels (10) and measurements are made of changes in blood volume in these vessels in rhythm with the pulse (7). By definition (11) this means that changes on the arterial side of the circulation are measured. Supporting evidence for this view has been provided by D'Agrosa and Hertzman who studied changes in individual vessels in animal mesentery (12). Light from the pulsemeter (which measures arterial pulsation) penetrates only a short distance and it is probable that it is the arteriolar pulse which is recorded.

Hertzman (13–15) has shown that the cutaneous volume pulse is a reliable indicator of arterial perfusion of the skin and the photoelectric plethysmograph has been used more recently by Cummings (16) to assess cutaneous circulation. It has been shown that photoelectric plethysmographic records of the blood volume pulse follow intravascular recordings very closely, both in shape and amplitude of the pulse (17). The recording circuit used in the present investigation is so arranged that an increase in pulse height indicates arteriolar dilatation and vice versa. Color changes themselves are not measured; for example the erythema distal to peripheral arterial occlusion is associated with reduction in the amplitude, or even absence, of cutaneous pulses.

The sensitivity of this instrument is such that pulsations can be recorded from virtually any part of the skin (9) and, provided the sensor is applied gently to the area being examined, it does not alter the skin or its circulation in any way, which is an important consideration when investigating skin blood flow. Pulse volume and blood flow in the digits show a near linear relationship (18) but in other areas, such as those here tested, this relationship is uncertain and so quantitative results were not obtainable with this instrument. Valid qualitative results can still be obtained however by comparing pulse heights from the same site both before and after a particular procedure (9), the area thus acting as its own control. In the present study it was felt that control site recordings should be taken from an adjacent area of normal skin at the same time that recordings were made from the irradiated site. A lapse of several hours between irradiation and recording might have made it difficult to compare records taken from the same site.

Lewis and Zotterman (19) observed capillary and venular dilatation with occasional dilatation of terminal arterioles in UV erythema but the dose employed greatly exceeded that necessary to produce a minimal erythema. Holti (20), using a mercury quartz-arc lamp wes able to detect arteriolar dilatation by noting an increase of skin temperature as early as 40 minutes after irradiation, but the dose of UV was probably large, based on the evidence that there was a short latent period of only 50 minutes between irradiation and the appearance of erythema.

Crockford *et al.* (21) were not able to detect increased blood flow using a strain gauge plethysmograph in the area of UV irradiated skin until relatively large doses of UV had been given and even then not until the erythema was well established. It should be mentioned that this method measures volume changes in a segment of a limb and it is possible that small increases in skin blood flow may not be detected.

A recent review concluded that UV erythema was due to active dilatation of superficial venules and capillaries and that arteriolar dilatation was not the primary physiological response (6). The evidence cited by the reviewers to support the lack of arteriolar dilatation was based on an earlier observation by Rothman (5), that epinephrine injected intradermally into UV erythema did not cause pallor. Our studies would support the opposite view, that arteriolar dilatation occurs as a response to UV radiation.

Van der Leun, who used an infra-red detector to monitor the changes in skin temperature from erythema at 300 nm, observed that a rise in temperature began between 3 and 4 hours after irradiation at a time when erythema was fully developed; although erythema was still present at 40 hours the temperature had returned to normal at that time (4). A dose of at least 3 MED was required before temperature elevation could be detected. He was unable to detect any increase in skin temperature with 250 nm erythema even with doses up to 30 × MED and h concluded that the mechanism of production of the two types of erythema was different. However Tronnier feels that skin temperature measurements are of little use in evaluating reactions to UV (22). Differences between 250 nm and 300 nm erythema have been well documented. The 250 nm erythema appears earlier and reaches its peak sooner than that from 300 nm. The color at 250 nm is pink-red while at 300 nm it is a deeper red, and if several times the MED is given at both wavelengths the increase in depth of color is greater at 300 nm than at 250 nm. Despite these differences our results indicate that erythema at both wavelengths is associated

with arteriolar dilatation as early as 1½ hours after irradiation. Erythema from 250 nm fades quicker than that from 300 nm and recordings at 250 nm 96 hours after irradiation, when the skin was macroscopically normal, showed that the arteriolar dilatation which had been present had subsided (Fig. 2D). The 300 nm erythema persisted and at 120 hours after irradiation, arteriolar dilatation was still present as shown in Fig. 2C.

Studies of vascular changes which occur in the latent period between UV irradiation and the appearance of erythema are few. Rothman, who discussed the paper by Daniels and Bergeron (23), made a reference to a "vasodilatory tendency" occurring in the latent period but gave no details. Levan *et al.* (24) measured the clearance on intradermal Na^{22} both before and after irradiation with a germicidal lamp (254 nm) using a dose large enough to produce erythema an hour later. Clearance of the isotope decreased immediately after irradiation, then returned to normal one hour later but increased two hours after erythema had developed. Clearance of intradermal radioactive materials would indicate the "nutritive effectiveness" of the circulation (25) and does not measure blood flow as such. Nevertheless this study would seem to indicate that some vascular change occurs immediately after irradiation with 254 nm.

Our results have shown that arteriolar dilatation occurs at all wavelengths tested and could be detected at the MED site in over 50% of the persons examined. On a number of occasions arteriolar dilatation could be detected at doses lower than the MED, i.e. at the minimal perceptible erythema. The earliest recordings, taken 2½ hours after irradiation with a dose of 3 MED, when erythema was just detectable, also showed increased pulsation at 250 nm and 300 nm.

The area of skin irradiated in the present study was small (0.3 x 0.3 cm) and the problems associated with monitoring such a small area may explain why arteriolar dilatation could not be detected at MED sites in all persons. If larger areas of skin are irradiated it may be possible to detect arteriolar changes earlier in the latent period between irradiation and the appearance of erythema and also to determine whether or not UV radiation has an immediate effect on cutaneous arterioles.

The results of I.D. epinephrine in the present study were quite different from those obtained by Rothman, who wss unable to obtain pallor in UV erythema with this drug (5). We were able to demonstrate paling of the erythema in each subject examined, the most marked change being seen at the MED site, but definite pallor developed at sites irradiated with larger doses of UV, even as much as 10 MED at 300 nm in one subject. We used 0.05 ml of 1 in 10,000 epinephrine and as Rothman gives no details of the dose used we are unable to explain the differences in the results. Epinephrine constricts venules as well as arterioles (26, 27) and much of the pallor that develops in the UV erythema after this drug may be due to venular constriction. However, pronounced arteriolar constriction does occur as indicated by pulse amplitude, and can be seen in Figure 2E and F which demonstrates the changes at 250 nm and 300 nm.

One may postulate that the difference in color of 250 nm and 300 nm erythema is due to greater venular dilatation in the latter, but we have demonstrated that arteriolar dilatation is a feature of both. If evaluation is limited to skin color alone, an erroneous impression of the state of the cutaneous arterioles may be obtained, as is seen in the delayed blanch from I.D. acetylcholine in atopic dermatitis where, despite pallor, arteriolar dilatation is present (9, 28).

Erythema is not necessarily associated with arteriolar dilatation and increased flow; as previously discussed, the erythema seen in arteriosclerotic peripheral vascular disease shows diminished or absent pulsations (unpublished observations). The pulsemeter in fact has a useful application in the investigation of patients with peripheral vascular disease.

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