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Visual Scoring System for Fluorescent Tracer Evaluation of Dermal Exposure to Pesticides

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Dermal exposure and absorption of pesticides has been recognized as a major occupational health problem for over 25 years (Durham and Wolfe 1962). The patch technique currently recommended as a standard protocol by the U.S. Environmental Protection Agency and the World Health Organization provides a useful means of estimating occupational exposures, but is limited by its reliance on chemical analysis and difficulties related to sample storage and transport (USEPA 1987; WHO 1982). There is also a substantial lag time between monitoring and the receipt of results. Recognition and control of dermal exposures can be enhanced significantly by an evaluation method which provides results on-site without chemical analyses. This paper reports on the development and testing of a visual scoring system for evaluating dermal exposure with fluorescent tracers. The system is designed to allow observers to translate subjective observations into a score based on a simple two-dimensional exposure matrix.

This work grows out of studies which have quantified dermal exposure by means of fluorescent tracers and a computer-based video imaging system (Fenske et al. 1985; 1986a; 1986b). These studies have demonstrated several important factors regarding dermal exposure: 1) exposure is highly variable rather than uniform over body regions, 2) exposure occurs to the hands despite the use of protective gloves, and 3) exposure to regions protected by garments is common and often constitutes a substantial fraction of total exposure.

Recent studies have confirmed that fluorescent tracer exposure during mixing and application procedures is representative of pesticide exposure (Fenske et al. 1986b). A high correlation (r=.91) has been demonstrated between fluorescent tracer deposition on skin

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and 72 hour excretion of malathion urinary metabolites during normal pesticide application (Fenske 1988). Thus, it appears that deposition of fluorescent tracers and pesticides on the skin are comparable, and that the fluorescent tracer technique has validity as a relative measure of dermal exposure. This method is being employed currently to evaluate protective clothing performance, exposure of pest control operators during termiticide applications and exposure during greenhouse applications.

In many field situations quantification by image analysis is neither necessary nor practical. Rather, investigators require a a rapid and simple method for comparing the performance of different types of equipment, protective clothing or work practices. Under such circumstances the use of fluorescent tracers can be combined with the visual scoring system presented here to produce semi-quantitative determinations.

MATERIALS AND METHODS

The fluorescent tracer technique was employed in the study of 24 workers conducting mixing and application activities in orange groves in the Central Valley of California. The fluorescent whitening agent, 4-methyl-7-diethylaminocoumarin, was added as a tracer. Each of the eight mixers added 300 grams of the tracer powder eight times to a 500 gallon airblast sprayer. Each of the 16 applicators sprayed four 500 gallon tanks.

At the end of the study period each worker was examined in a darkened room under longwave ultraviolet light (UV-A or "black light"), and exposure patterns were recorded with a video imaging system. Illumination was provided by two sets of 122 cm (4 foot) BLB bulbs covered by longwave UV-selective glass filters positioned 90 cm from the subject. These lamps produce approximately 200 uwatts/sq cm UV-A at the subject plane. The imaging system (TECMAR RT + MI) consists of a microcomputer with digitizing capabilities interfaced with a television camera (RCA TC2000). The imaging system has a resolution of 128 x 128 picture elements, and thus produces an image with 16,384 discrete units. Each picture element is assigned a rank of 0-16 depending on the amount of light detected by the camera. The camera is equipped with a Wratten 2E filter (Kodak) to eliminate detection of UV-A illumination. Video images of exposed skin surfaces are recorded by the computer onto disk, and can be displayed subsequently on a television monitor for analysis.

Images of exposure to the hands and heads of the 24 workers were recorded at a camera-to-subject distance of 70 cm with an aperture of f/1.4. Five sets of imaging

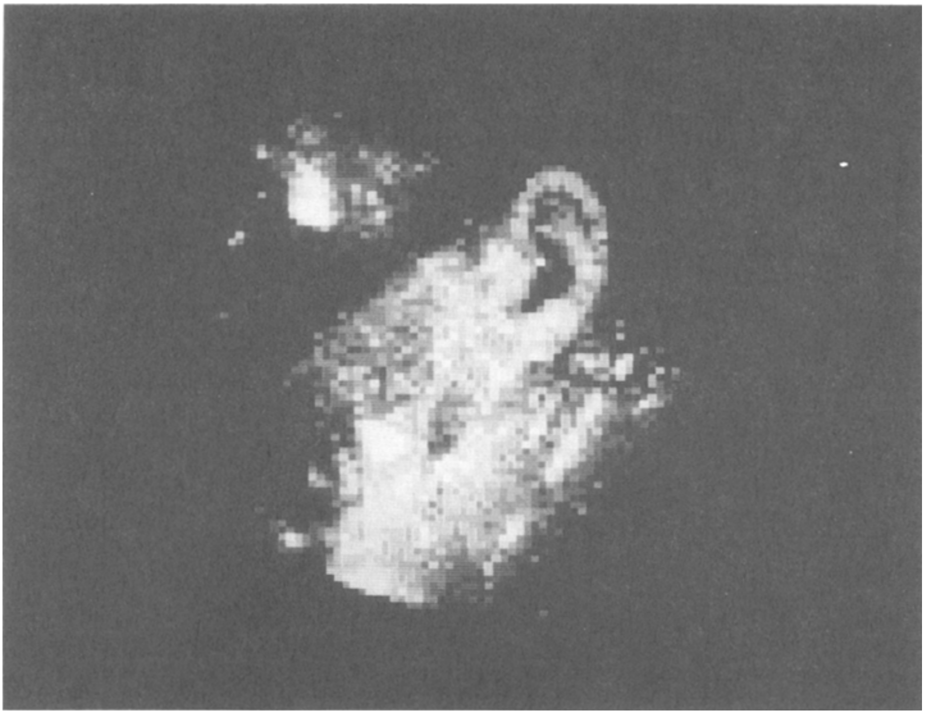

Figure 1. Left side of applicator face; score = 20

data were selected for analysis with the scoring system: the front, left side and right side of the face, and the palms and backs of the hands. These skin surfaces received substantial exposure during the study, and provided a wide range of exposure values. Thus, a total of 120 images were evaluated by the scoring system. Figures 1 and 2 illustrate the fluorescent tracer patterns collected with this technique.

The video images were transformed to slides by photographing each image as it was displayed on the television monitor. The photographs were taken in a dark room with a tripod-mounted single lens reflex camera (Cannon 240E). Photographic conditions were standardized as follows: ASA 400 Ektachrome slide film; camera-to-screen distance=30 cm; shutter speed=1/30 sec aperture=f/2.0. All film was from the same batch, and all slides were developed in the same run by a commercial laboratory. Thus, the slides reproduced the exposure patterns evident in the video images.

The scoring system is presented as a matrix in Table 1. The ordinate of the matrix is Exposed Area, and the abscissa is Exposure Intensity. Each of these characteristics of exposure is represented by a scale of 5 possible scores. Exposed Area has been subdivided by

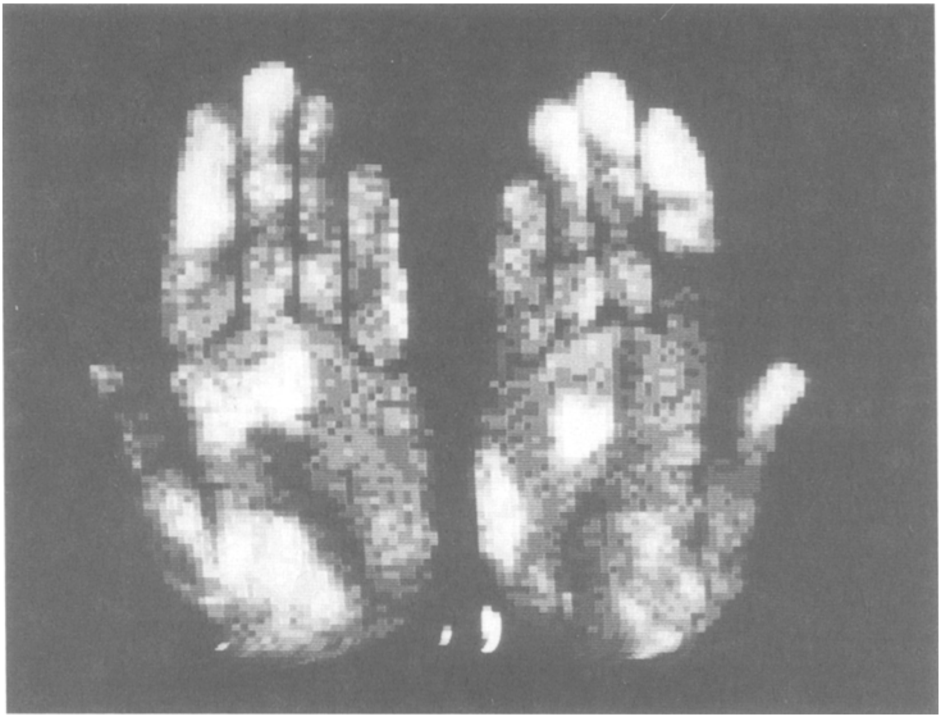

Figure 2. Palms of mixer; score = 16

percent: <20% of the body surface being exposed receives a score of "1", whereas exposure to >80% is scored as "5". Similarly, the Exposure Intensity scale represents a range of exposures from low to high. The product of these two ranks results in a final score for the image. The values presented within the matrix represent all of the possible scores with the system, ranging from 1 to 25. Use of the product of these ranks is based on the

Table 1. Exposure Evaluation Matrix[a]

Area Exposed (%)						
80-100	5	5	10	15	20	25
60-80	4	4	8	12	16	20
40-60	3	3	6	9	12	15
20-40	2	2	4	6	8	10
0-20	1	1	2	3	4	5
	score	1	2	3	4	5
		Low		Moderate		High
				Exposure Intensity		

a: scores within the matrix are the product of Area Exposed score and Exposure Intensity score.

assumption that the total amount of exposure is best represented by equal weighting of Exposed Area and Exposure Intensity.

A total score for a body part such as the hands or head is calculated by adding the scores of the images. In the case of the hands, the maximum score for the two images is 50, whereas for the head the maximum score for three images is 75. Use of the sum of the images for a total score for the body part assumes that all of the images are equal contributors to total exposure. Total scores for different body parts cannot be compared directly with this system (e.g., head vs. hands), since these scores are dependent on surface area and the number of images examined.

Five members of the University staff were asked to serve as observers in testing the scoring system. None of them had participated in the field study or in the production of slides from the video images. The observers were first shown all of the images rapidly to provide them with a sense of the range of exposures to be scored. The images were then presented sequentially, with the observers ranking each image first according to the extensiveness of the exposure over the body surface displayed (Exposed Area), and subsequently according to the overall intensity of the exposure (Exposure Intensity). Observers were asked to ignore the natural fluorescence of the fingernails evident for many of the workers.

The scores generated by this evaluation system were analyzed to determine the consistency between pairs of individual observers, and the consistency of the observer scores with exposure measurements generated by the video imaging system. The final scores for images and the total scores for body parts are not continuous; i.e., there are no scores of 7,11,13,14, etc. Thus, nonparametric statistical tests were applied to the data, including the Spearman Rank Correlation Test to test for associations, and the Mann-Whitney U Test (Wilcoxon Test) to test for differences between mean values. For Analysis of Variance tests raw data values were transformed into rank scores. The F-test performed on rank data is equivalent to the Kruskal-Wallis test.

RESULTS AND DISCUSSION

Inter-observer variability was examined by calculating the Spearman Rank Correlation statistic for the 10 possible pairings of observers. This analysis provides a measure of correspondence in individual perceptions of exposure patterns. Results for both the hand and head exposures are presented in Table 2. All correlations were highly significant ($p<.001$), exhibiting ranges of r(s)=.84-.98 for the hands, and from r(s)=.68-.94 for the head. Observer #2 displayed relatively poor consistency with the other four observers when evaluating head exposure. The four observer pairs for this body part containing Observer #2 were the four lowest correlations. The remaining six pairs range from r(s)=.83-.94, nearly identical to the range for the hands.

Table 2. Inter-Observer Comparison of Scores[a]

Observer Pair	HANDS r_s	HEAD r_s
1 v 2	.89	.82
1 v 3	.92	.89
1 v 4	.97	.88
1 v 5	.95	.83
2 v 3	.84	.74
2 v 4	.91	.70
2 v 5	.86	.68
3 v 4	.88	.94
3 v 5	.84	.88
4 v 5	.98	.93
Range	.84 - .98	.68 - .94

a: Spearman Rank Correlation; N = 24; p <.001 all cases

The observer scores can also be compared to the measurements of fluorescent tracer exposure collected with the video imaging system. Table 3 presents the Spearman Rank Correlation statistics for each observer and the imaging data. All of the correlations are statistically significant (p<.001), ranging from r(s) = .85 - .97 for the hands, and from r(s) = .83 - .90 for the head. While Observer #2 has the lowest correlation with the imaging data for head exposure, the correlation is much higher than those resulting from the inter-observer

Table 3. Observer Scores vs. Video Imaging Data[a]

Observer	Hands r_s	Head r_s
1	.92	.86
2	.91	.83
3	.85	.87
4	.97	.90
5	.94	.90
Range	.85 - .97	.83 - .90
Mean	.92	.92

a: Spearman Rank Correlation; N = 24; p <.001 all cases

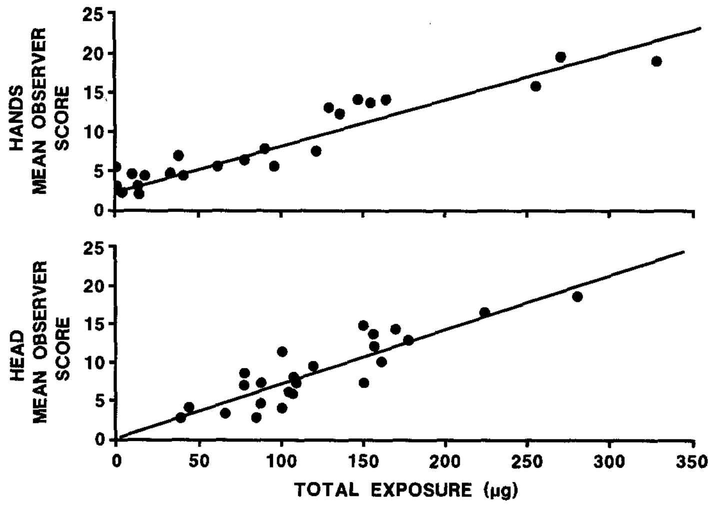

Figure 3. Correlation of mean observer scores for hands and head with video imaging data

comparisons, and is similar to those of the other observers. Thus, each observer was able to rank the exposure for both body parts successfully when judged against the ranks generated by the imaging data.

The correlations of mean observer scores and imaging data for both the head and hands are high (r(s) = .92). These associations are presented in Figure 3, where the mean observer scores for both the hands and head have been plotted against the imaging data. The total scores for both body parts have been normalized to the scale of 0-25 (hand score divided by two, head score divided by three) to allow a direct comparison.

The range of hand exposures (0-329 ug) is greater than that of the head exposures (39-281 ug), and this difference is reflected in the range of the mean observer scores (2-20 and 3-19, respectively). A number of the workers received little or no exposure to the hands due to the use of protective gloves, whereas the face and neck were unprotected. However, when hand exposure did occur it resulted in relatively high exposures.

Two important differences in exposure patterns were documented with the imaging system analysis: palm vs. back-of-hand exposure and mixer vs. applicator exposure. The ability of the scoring system to differentiate these exposure patterns provides a test of its sensitivity. First, as presented in Table 4, the imaging data demonstrate that exposure to the palms of the hands was 2.5-fold greater than exposure to the backs of the hands (70 ug vs. 27 ug, Mann-Whitney U Test, $p<.05$). The mean observer scores demonstrate a 1.8-fold difference, with exposure to the palms receiving an average score of 10.7, while exposure to the backs of the hands received an average score of 5.8 (Mann-Whitney U Test, $p<.01$). The Mann-Whitney score for each of the five individual observers also indicated greater exposure for the palms. However, only three of the five observer scores produced statistically significant differences.

Table 4. Palm versus Back-of-Hand Exposure Comparison

Evaluation System	Mean Palms	Mean Backs	Z[a]	p-value
Imaging System (ug)	70.3	26.8	1.82	<.05
Scoring System	10.7	5.8	2.69	<.01

a: Mann-Whitney U test; N = 24

Table 5 presents a comparison of exposure values for mixers and applicators. The average exposure to mixers was more than four times greater than the average applicator exposure (187 ug and 44 ug, respectively; ANOVA of ranks, $p<.0001$). The scoring system was able to demonstrate this same difference consistently. The mean observer scores differed nearly 3-fold (14.2 and 5.3, mixers and applicators, respectively; Rank-ANOVA, $p<.0001$). Each of the five individual observer scores demonstrated the same difference with statistical significance.

Table 5. Mixer versus Applicator Exposure Comparison

Evaluation System	Mean Mix	Mean Apply	F-test[a]	p-value
Imaging System (ug)	186.6	44.4	23.1	<.0001
Scoring System	14.2	5.3	24.0	<.0001

a: Rank-ANOVA; N = 24

In summary, it appears that an individual observer can employ the scoring system to accurately rank exposures, and to make distinctions between dermal exposure patterns comparable to those produced by the imaging system. However, multiple observers are required to achieve a similar level of sensitivity when the differences are not large. Thus, the use of this method on-site will require the presence of several observers to evaluate subjects following exposure. Alternatively, investigators can record the exposure patterns on slides through standard photography, or by video taping and playback on a video tape recorder with single frame freezing capabilities. Several photographic parameters need to be standardized to insure comparability among the exposure patterns of different body parts and different workers, including uniform UV-A illumination over the skin surface, care in positioning the subject, and a fixed camera-to-subject distance.

The fluorescent tracer scoring system allows a semi-quantitative characterization of exposure deposition patterns on the skin. While this method is not as sensitive as quantitative imaging analysis, its simplicity and practical advantages make it an attractive alternative under many field study conditions. Its use in conjunction with the patch technique or biological monitoring can provide valuable supplementary information regarding sources of dermal exposure. The scoring system can serve as a basis for industrial hygiene recommendations related to equipment type, equipment performance, protective clothing use, protective clothing performance, work activity and work practices. The procedure also serves an educational function in that workers enter into the evaluation process and learn of ways they might prevent future exposures.

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