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Processes Involved in the Development of Latent Fingerprints Using the Cyanoacrylate Fuming Method*

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ABSTRACT: Chemical processes involved in the development of latent fingerprints using the cyanoacrylate fuming method have been studied. Two major types of latent prints have been investigated—clean and oily prints. Scanning electron microscopy (SEM) has been used as a tool for determining the morphology of the polymer developed separately on clean and oily prints after cyanoacrylate fuming. A correlation between the chemical composition of an aged latent fingerprint, prior to development, and the quality of a developed fingerprint has been observed in the morphology. The moisture in the print prior to fuming has been found to be more important than the moisture in the air during fuming for the development of a useful latent print. In addition, the amount of time required to develop a high quality latent print has been found to be within 2 min. The cyanoacrylate polymerization process is extremely rapid. When heat is used to accelerate the fuming process, typically a period of 2 min is required to develop the print. The optimum development time depends upon the concentration of cyanoacrylate vapors within the enclosure.

KEYWORDS: forensic science, latent fingerprint, latent-print aging, polymerization, polymer, morphology, cyanoacrylate, superglue

Since the late 1970s, cyanoacrylate esters (superglue) have been used as an effective means of developing latent fingerprints. Initially, latent prints were developed at ambient temperature and pressure through exposure to low concentrations of the cyanoacrylate vapors within an enclosure such as a fish tank (1,2). Print development using this technique required long exposure times, and often produced a high background of polymer. Several research articles aimed at reducing exposure times followed. Kendall and Rehn published an article detailing a rapid method of superglue fuming using absorbent cotton and sodium hydroxide as a means to accelerate the fuming process and reduce the development time to approximately 1 h (3). Around the same time, several reports described the use of heat as a means of accelerating the fuming process (4–6). To date, heat fuming of the cyanoacrylate ester, in an aluminum container, which also acts as a polymerization retardant (7), remains a widely used method for developing latent prints. When using this method, a lower amount of time is actually required to develop a latent print without the buildup of a polymer background. Latent fingerprints currently developed by the Federal Bureau of Investigation's (FBI) Latent Print Unit are processed using the "microburst method." When using this technique, the cyanoacrylate ester is heated in a small chamber at a hot temperature (approximately 400°C) to quickly produce a high concentration of the cyanoacrylate vapor (8). A piece of evidence is repeatedly placed in the fuming chamber and developed for 30 s periods, for a maximum time of 2 min, until the prints are developed. The "microburst method" allows the ridges of the latent print to be developed at a maximum rate, while maintaining a low background of polymer.

Vacuum deposition is an alternative method, predominately used outside of the United States, for developing latent prints with the cyanoacrylate ester in the absence of heat (9,10). In using vacuum deposition, the cyanoacrylate ester is placed inside of a vacuum chamber along with the item to be fumed. With a vacuum pump, the pressure inside of the closed system is reduced to approximately 1 torr. Once the desired pressure is achieved, the container is sealed, allowing the cyanoacrylate ester to vaporize at room temperature under reduced pressure. Prints developed by vacuum deposition tend to be translucent, requiring a secondary treatment such as fluorescent-dye staining for print visualization (10).

Although cyanoacrylate fuming has proven to be an extremely successful method for developing latent fingerprints, problems have been encountered with its use. Environmental factors appear to play an important role in the success of developing prints using cyanoacrylate esters. In arid areas, such as Arizona, the success rate for developing prints with cyanoacrylate esters is much lower than in more humid areas. In addition, whiter, more easily visualized prints were typically formed when fuming at high humidity levels. These observations led to the heat/humidity method of fuming in which a humidity level of approximately 80% is maintained (10).

Differences in the ability to detect children and adult fingerprints, after a 24 h period, were identified by a Knoxville crimi-

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nologist, Art Bohanan (11). As a result of his observation, research was initiated at Oak Ridge National Laboratory under the direction of Dr. Michelle Buchanan to chemically profile the fingerprint residue from adults and children. Findings from this research were in agreement with Stewart's et al. research on the sebaceous gland activity and serum dehydroepiandrosterone sulfate levels in boys and girls (11,12). Apparently sebum is not secreted in young children prior to the production of adrenal androgens. Production of these androgens typically occurs between the ages of seven to ten. The materials secreted, before generating adrenal androgens, consist largely of volatile components such as free fatty acids (11) and cholesterol esters (apparently from the recycling of cholesterol released when sebaceous cell membranes break down) (13). After the age of 7 to 10 years, the sebaceous glands excrete sebum, an oily material. Most of the lipids on the skin surface come from sebaceous glands (14). Surface lipids are reported to contain squalene (10%), sterol esters (2.5%), sterols (1.5%), wax esters (22%), triacyl glycerols (25%), di- and monoacyl glycerols (10%), unesterified fatty acids (25%), and 4% unidentified constituents.

Sebaceous glands are not located within the finger/palm regions of the hands; however, sebaceous material is a typical composition of a latent fingerprint (11). Most likely, sebum is transferred to the hand and fingers from contact with other sebum-producing regions of the body such as the face, hair, and neck. Only eccrine glands are located on the palm and finger regions. Eccrine sweat is largely comprised of water with traces of salts, free amino acids, sodium lactate, urea, mucoproteins (mucin-type glycoproteins) (15–17), and ammonia, but does not contain a significant quantity of lipid material (18).

In order to explain why fuming conditions, environmental factors, and latent print composition influence the ability to successfully develop a latent fingerprint using the cyanoacrylate fuming method, research was initiated to determine the actual chemical processes involved. Two fingerprint extremes were evaluated—clean prints and oily prints. Clean prints represented the latent material deposited by a child or an individual with freshly cleaned hands, and oily prints represented the latent material deposited by an individual with sebum-coated fingers. Ideally, clean prints contain components of eccrine sweat, where oily prints contain sebaceous sweat in addition to eccrine sweat.

Materials and Methods

Instrumentation and Chemicals

Molecular weight studies were performed on cyanoacrylate-developed, clean and oily fingerprints using an Auto Vap AS 2000 GPC system (ABC Laboratories, Inc., Columbia, MO) packed with SX-1 resin (Biorad Laboratories, Hercules, CA). Polystyrene calibration standards having molecular weights of 800, 2000, and 100,000 (Pressure Chemical Co., Pittsburgh, PA) were dissolved in distilled HPLC grade tetrahydrofuran (JT Baker, Phillipsburg, NJ) for use in determining cyanoacrylate-developed clean and oily print molecular weight distributions.

Time-study images were obtained using a Panasonic GP-KR22 CCD, Navitar 7000 Zoom lens, and an Interface Industrial Image capture board equipped with Oculus TCI-Pro Version 2.2 imaging software (Edmund Industrial Optics, Barrington, NJ). High magnification images were obtained using a Tracor ADEM Scanning Electron Microscope (Noran Instruments, Madison, WI).

Latent Print Preparation and Cyanoacrylate Fuming Method

Latent prints were placed on cleaned and dried 1.25 in. diameter stainless steel planchettes (A F Murphy Die & Machine Co., North Quincy, MA) or 2 in. by 2 in. glass slides (VWR Scientific Products, West Chester, PA). Clean prints were prepared by thoroughly washing, rinsing, and drying hands, and swiping thumbs with ethyl alcohol (AAPER Alcohol and Chemical Co., Shelbyville, KY) prior to placing the print on the development medium. Oily prints were prepared by swiping a cleaned thumb across oily regions (forehead, nose, neck, or hair) prior to placing the print on the development medium.

Unless otherwise noted, latent fingerprints were developed by placing approximately 1 g of ethyl 2-cyanoacrylate (Sirchie,

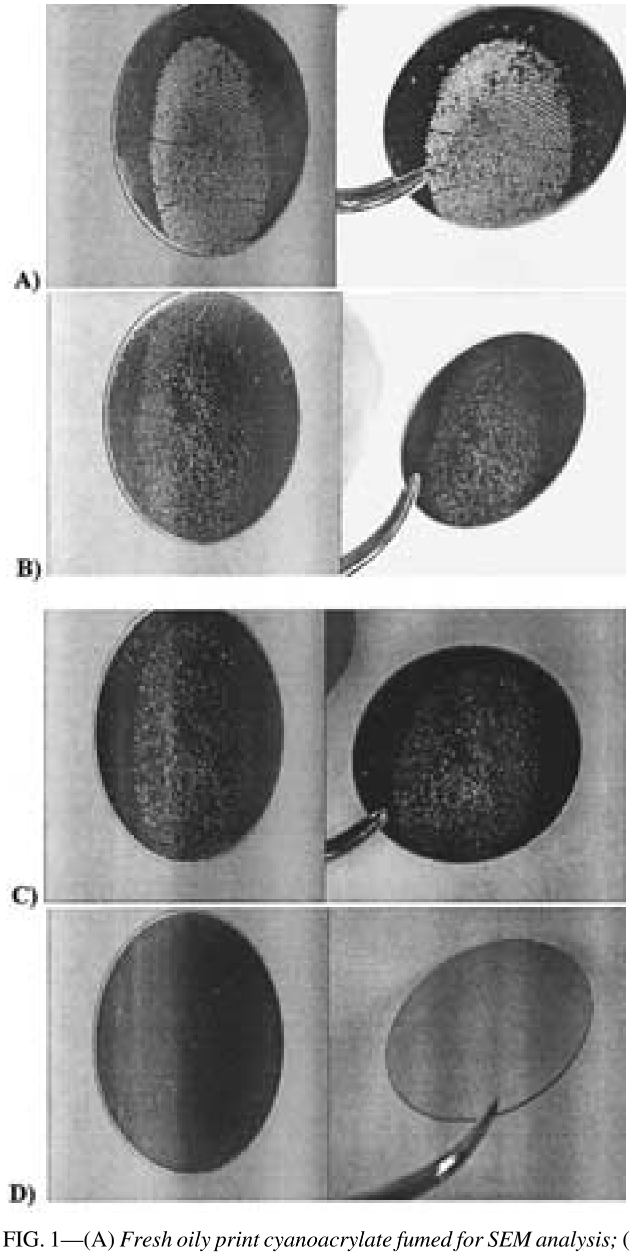

FIG. 1—(A) *Fresh oily print cyanoacrylate fumed for SEM analysis;* (B) *two-day-old oily print cyanoacrylate fumed for SEM analysis. The print was aged prior to fuming;* (C) *fresh clean print cyanoacrylate fumed for SEM analysis; and* (D) *two-day-old clean print cyanoacrylate fumed for SEM analysis. The print was aged prior to fuming.*

Youngsville, NC) in an aluminum weighing dish (VWR Scientific Products, West Chester, PA), and positioning the dish on a hotplate heated to a surface temperature of 150°C. Once the white fumes were visible, the item being developed was placed over the cyanoacrylate, in the fumes, for a given period of time. Sirchie "Hi-Fi" Volcano silver/black latent print powder was used to enhance images developed on glass slides when pictures were taken against a white background. Black felt was used as a dark background to image nondusted prints developed on glass.

Results and Discussion

Initially, the chemical processes and critical parameters involved in successfully developing latent prints using the cyanoacrylate fuming method were not known and were being evaluated. Preliminary development experiments were conducted on both clean and oily prints in environments ranging from 19 to 72% humidity, while exposing the prints to ethyl 2-cyanoacrylate fumes generated on a hotplate (surface temperature of 150°C) inside a 15 in. by 15 in. by 12.5 in. Plexiglas box. All developed latent fingerprints (freshly prepared) were of excellent quality, regardless of the humidity level. The fact that good quality latent prints were obtained at such low humidity levels was unexpected.

During the early stages of this research, humidity did not appear to play a major role in the development of latent prints; however, the quality of developed prints did appear to decrease with the print age prior to fuming. Changes in the characteristics of fumed oily and clean prints, fresh and aged, prepared for SEM analysis are apparent in Fig. 1. A difference in visible quality of oily prints (Figs. 1*a* and 1*b*) and clean prints (Figs. 1*c* and 1*d*) is notable when comparing fresh and two-day-old prints that have been developed. Fumed fresh prints, clean and oily, yield a visible grainy-white polymer on the ridges of the print. The polymerized print ridges are high in contrast, especially when developed on a dark surface, compared to the groove and background regions. Aged prints lose the grainy-white appearance, and become more translucent, which greatly reduces the contrast between the ridge and background areas.

Changes in polymer formations were also noted between fumed clean and oily prints, fresh and aged, when observed by SEM under 5000× magnification. Figure 2*a* illustrates the structure obtained when a fresh clean print was developed using cyanoacrylate esters, whereas Fig. 2*b* illustrates the structures developed when the clean print was allowed to age two days prior to fuming. In order to understand the aging processes that cause these changes in polymer formations, the effect of atmospheric conditions on clean latent fingerprints was studied. Pairs of clean prints, on stainless steel planchettes, were exposed to one of the following conditions for a period of one to four days prior to fuming: normal conditions (blank), high humidity (90+%), low humidity (~7%), enriched O_2, enriched N_2, and enriched CO_2. Results indicated that high levels of O_2, N_2, and CO_2 made very little difference in visible quality of the print upon development compared to the blank. The prints aged one to two days under high humidity tended to have slightly better visible quality than the blank upon fuming, but the quality tended to merge toward that of the blank on days three and four. The low-humidity conditions yielded a major difference in developed print quality compared to the blank. Prints aged one through four days in low humidity did not develop when exposed to the cyanoacrylate vapor. In fact, when the low humidity experiment was repeated with the print exposure evaluated on an hour-by-hour basis, no print was developed after being exposed to approximately 7% humidity for four hours or longer. Apparently, the initiators of cyanoacrylate polymerization are water-soluble components, which are less effective when the water is removed. Maintaining the clean prints in a high-humidity environments slows down this aging process, but does not inhibit it.

SEM images of how the clean-print noodle structures are formed and developed were captured for fuming intervals of 20 to 120 s. The polymer formations are first initiated within a 20 s period as can be seen in Fig. 3*a*. Once the base of the polymer structure is formed, the noodle-type structure grows very rapidly. After polymer initiation, Figs. 3*b* to 3*d* suggest that the process is completed within 45 to 120 s. Gel permeation chromatography (GPC) analysis of the clean-print polymer structures, dissolved in THF, revealed three distinct molecular weight ranges including a 2000, 100,000, and $>$100,000 distribution. The 100,000 and $>$100,000 distributions would be consistent with the long noodle-type structure illustrated in Fig 3; whereas, the 2000 distribution may be attributed to the spherical structures that are carried by the developing polymers in Fig. 3*b*, and carried by a smaller portion of the structures in Fig. 3*d*.

SEM images of fresh and two-day old cyanoacrylate fumed oily prints are illustrated in Fig. 4. The noodle-type structures were no

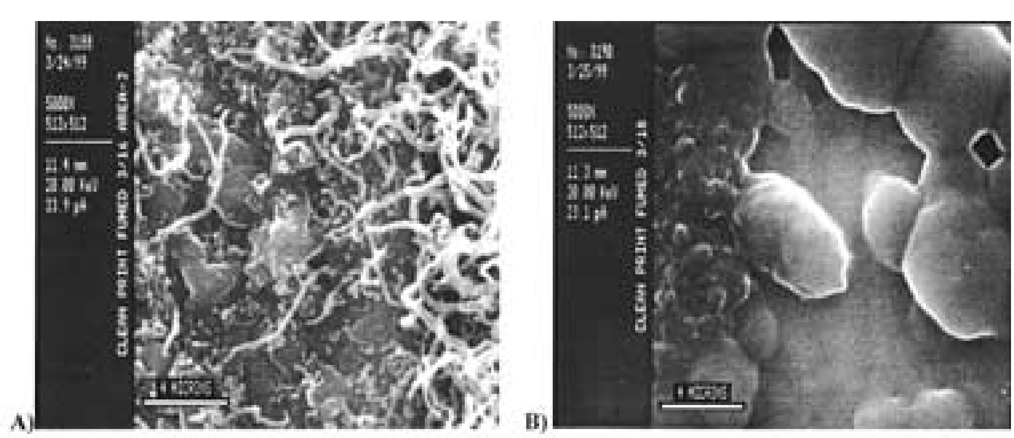

FIG. 2—(A) *SEM image of a fresh, cyanoacrylate fumed clean print at a 5000× magnification;* (B) *SEM image of a cyanoacrylate fumed two-day-old clean print at a 5000× magnification. The print was aged prior to fuming.*

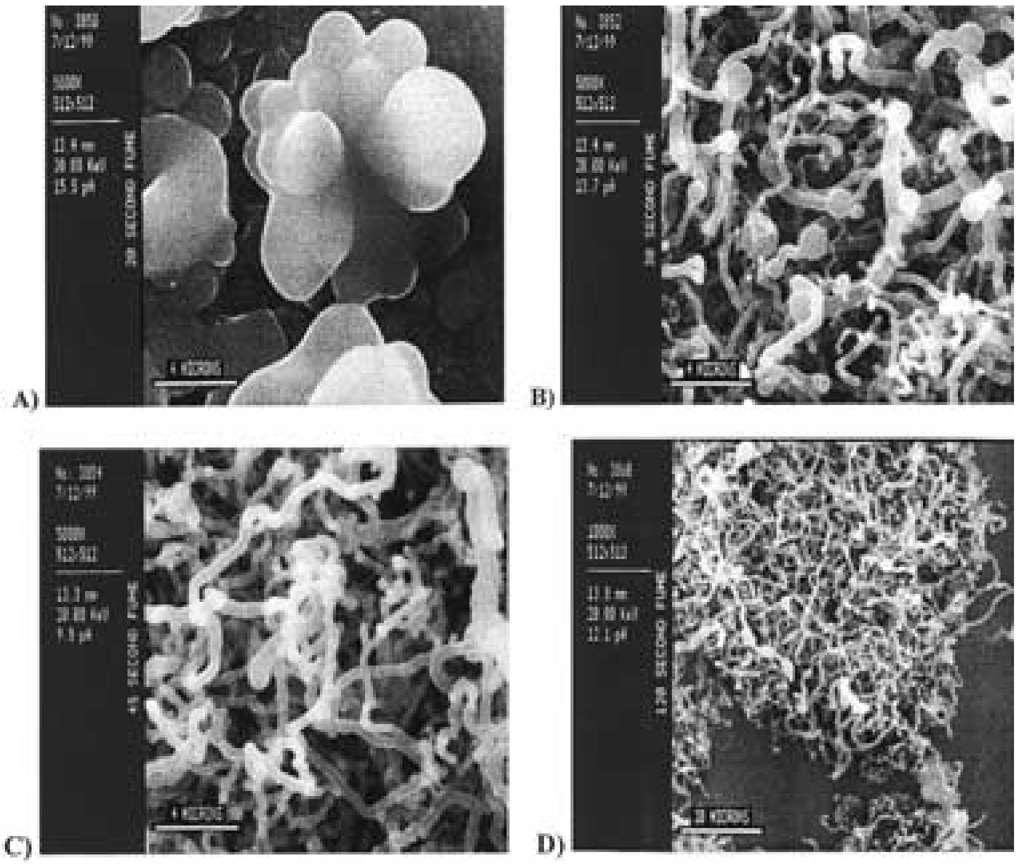

FIG. 3—*Images of the polymer formations developed during the cyanoacrylate fuming of a clean print. Clean print exposed to cyanoacrylate vapors for:* (A) *20 s,* (B) *30 s,* (C) *45 s, and* (D) *120 s.*

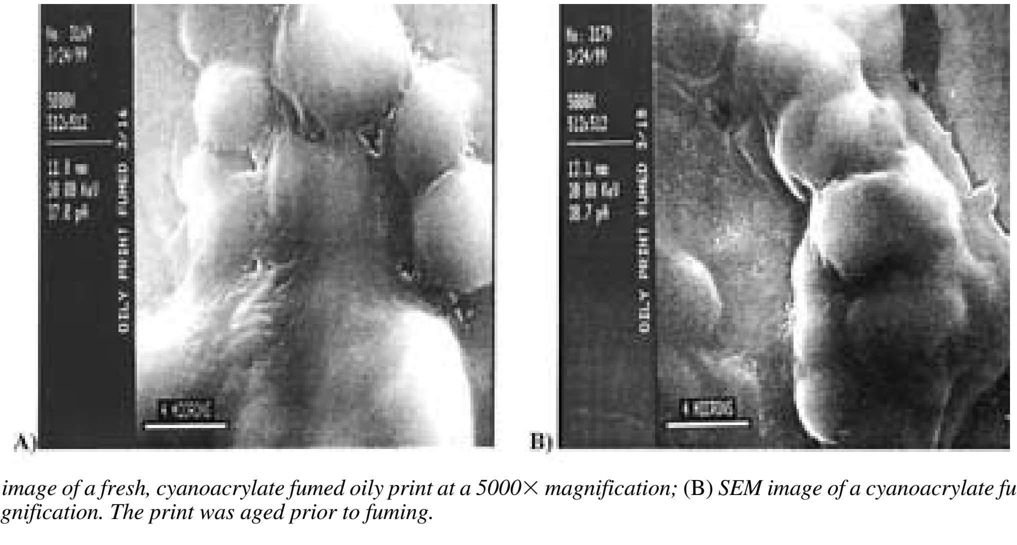

FIG. 4—(A) *SEM image of a fresh, cyanoacrylate fumed oily print at a 5000× magnification;* (B) *SEM image of a cyanoacrylate fumed two-day-old oily print at a 5000× magnification. The print was aged prior to fuming.*

longer present in the developed oily prints; however, capsule-type formations were observed. The differences in morphology between clean and oily prints may be explained by considering the composition of the clean and oily latent-print residues. The clean-print composition, as mentioned earlier, is aqueous based. The oily print residue contains the aqueous material, as well as surface sebum. The sebum constituents make up an organic phase containing oils and fatty acids. The fatty acids act as a type of emulsifier for the aqueous and oily phases. Upon fuming, the constituents required for an emulsion polymerization are present: oil, surfactant, initiator, aqueous phase, and monomer. The oily-print polymer formations obtained are similar in structure to the polyethyl-2-cyanoacrylate nanocapsules that are prepared by emulsion polymerization and used as a biocompatible and biodegradable colloidal drug delivery system (19). Regardless of whether noodles or capsules are formed on the ridge of a latent print, the polymer structure is an effective means of scattering light, thus producing the white visible print image rather than the clear translucent image.

The effects of oily-print aging are apparent in Figs. 4*a* and 4*b*. The sphere size in the fresh print ranges from 3 to 6 μm, and the two-day-old sphere size ranges from 2 to 4 μm. GPC results were consistent with the 100,000 and >100,000 distributions of the clean-print noodle structure (excluding the 2000 distribution thought to correlate with the spherical structure at the visible end of the noodle).

The first indication that the cyanoacrylate monomer was condensing in the background regions during cyanoacrylate fuming was noted in Fig. 5. The planchette containing a fresh oily print was etched prior to SEM analysis. The etching caused a crack in the clear, groove area on the opposite side of the disk. Apparently, the cyanoacrylate vapor condensed on the cooler background regions during fuming, accumulating at a rate slower than that of the propagating polymer. Figure 5 is a good illustration of the fact that overexposure to the cyanoacrylate vapor will only lead to the background being developed to a point in which the latent print may become obscured.

The realization that the quality of a developed latent fingerprint depends on the chemical composition of the print, rather than the fuming conditions under which it was developed, led to a clean and oily print aging study. In this study, latent clean and oily prints were naturally aged under normal room temperature and humidity over time while stored in an open container located in a filing cabinet drawer. Figure 6 depicts the results obtained in the clean-print study. Clean prints were naturally aged for a period of 1 to 42 days prior to fuming with cyanoacrylate vapors. Images of the developed prints were captured against a dark background, without dusting, to view the white polymer on the ridges, and against a white background, to portray the three-dimensional characteristic of the polymer formation. Figure 6*a* illustrates the grainy, white polymer formation and the three-dimensional structure of a one-day-old developed clean print. The characteristics of a two-day-old developed print, Fig. 6*b,* are remarkably different than the one-day-old print. The three-dimensional structure was greatly diminished, and the grainy, white ridge detail was absent. The quality of developed clean prints did not improve over time in comparison to Fig. 6*b*. After two weeks, the amount of visible polymer was reduced to only faint traces. Regeneration of a clean print, after aging for 14 days, through exposure to high humidity, was attempted without success. However, after aging a clean print for 41 days, regeneration through exposure to acetic acid vapors was achieved, as illustrated in Fig. 6*c*. The actual mechanism responsible for the successful print regeneration is not understood at this time. Possibly, the mucoproteins within the clean print act as a mucoprotein barrier against aqueous hydration once the print has become dehydrated. The ability to regenerate the print with acetic-acid vapors may be due to the organic properties of the acid, allowing the vapors to penetrate the barrier and once again resolvate the initiators.

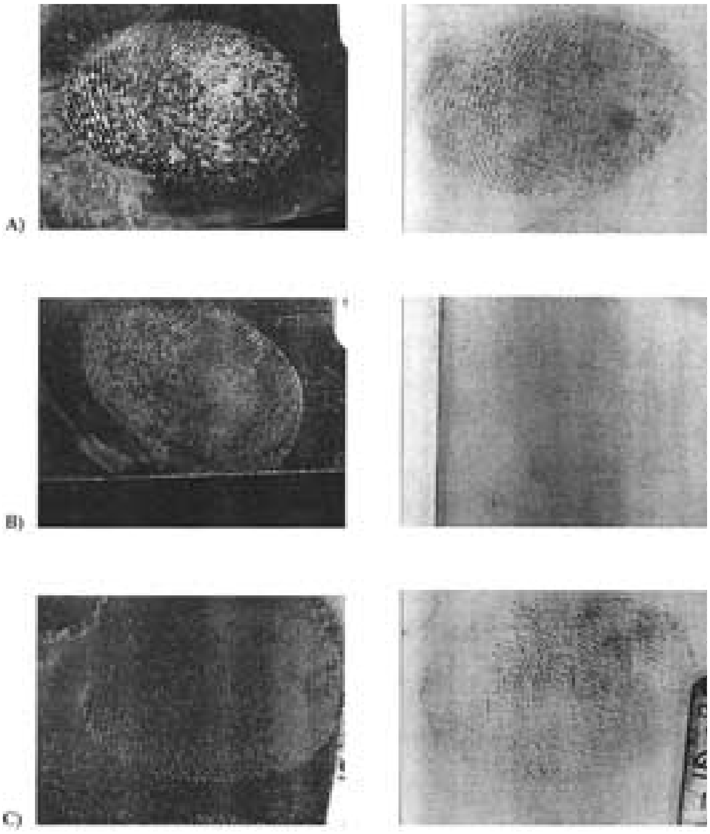

FIG. 6—*Cyanoacrylate developed clean prints taken against dark backgrounds (nondusted to demonstrate the presence of polymer) and white backgrounds (dusted to demonstrate the depth of the developed prints).* (A) *Developed fresh print,* (B) *developed one-day-old print, and* (C) *developed 41-day-old print regenerated using acetic acid vapors.*

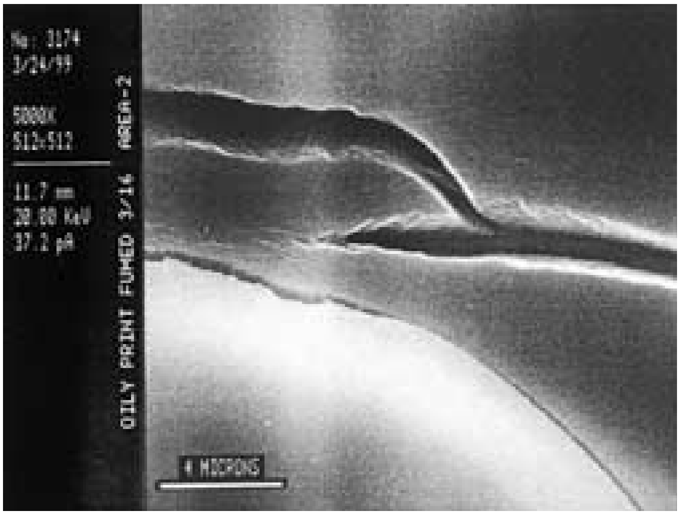

FIG. 5—*Oily print developed by cyanoacrylate fuming. A crack in the groove region of the print was the first indication that the cyanoacrylate ester was also being deposited on the background regions. The ridges of the latent print are polymerized at a faster rate than the background due to the polymer growth process during fuming.*

The oily-print aging results were not as dramatic as the results obtained in the clean-print aging study. Aged, oily prints were still distinguishable for prints as old as six months prior to fuming. The quality of the six-month-old developed print (Fig. 7*d*) had greatly degraded compared to the one-day-old print (Fig. 7*a*), but areas of good definition were still present. The appearance of chalky white film, within the groove region, began appearing on the one-month-old print (Fig. 7*c*), and became more evident on older prints.

The ability to develop good quality oily prints, older than two days, may be attributed to the presence of fatty acids and mono-

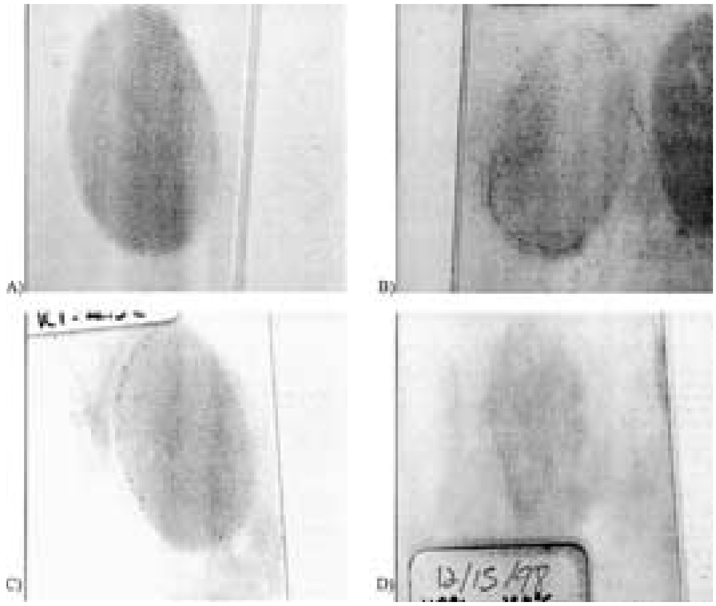

FIG. 7—*Cyanoacrylate developed oily prints aged:* (A) *one day,* (B) *one week,* (C) *one month, and* (D) *six months.*

and diacyl glycerols within the sebaceous material of the print. These components have the potential to hold moisture within the print residue and to prevent dehydration. Others (14) have proposed a similar mechanism in which free fatty acids and mono- and diacyl glycerols, from the surface sebum, help retain moisture in skin through the formation of thin-film barriers, thus delaying evaporation. In addition, the presence of mono- and diacyl glycerols, as well as glycerol, released during hydrolysis of the triacyl glycerols helps to retain moisture in skin due to their hygroscopic nature (14). The presence of hygroscopic material within the oily latent print could explain the improved quality of cyanoacrylate developed aged oily prints fumed at high humidity levels. However, the actual amount of humidity must be optimized in order to decrease background development. Potentially, rehydration prior to, rather than during, processing could prove more beneficial to the overall quality of the developed print. The formation of translucent polymers on the ridges of the latent fingerprint using the vacuum deposition method is attributed to the dehydration of the fingerprint under vacuum during processing.

Conclusion

Both visual and microscopic differences in the ethyl 2-cyanoacrylate polymer formations on clean and oily prints have been presented. Distinct differences in the chemical behavior and aging effects of the two print-type extremes have been noted. It is perceived that the clean print findings may provide a model for the print behavior of a prepubescent child. The actual amount of sebaceous material in the content of an adult's print would vary from individual to individual, depending on skin type, personal hygiene, etc. For this reason, the chemical and physical properties of an adult print would lie anywhere between the two extremes reported.

Latent fingerprint research efforts relating to the cyanoacrylate fuming process are ongoing. Actual polymerization initiators have been identified, and will be reported in the near future. Efforts to understand the degradation process of both clean and oily prints are underway in hopes to develop a universal regeneration mechanism.

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