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ENHANCED LATENT FINGERPRINT DETECTION IN
MISSING AND EXPLOITED CHILDREN INVESTIGATIONS

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ENHANCED LATENT FINGERPRINT DETECTION IN MISSING AND EXPLOITED CHILDREN INVESTIGATIONS

By

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ABSTRACT

ENHANCED LATENT FINGERPRINT DETECTION IN MISSING AND EXPLOITED CHILDREN INVESTIGATIONS

By

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Cyanoacrylate fuming is one of the most common and effective methods of developing latent fingerprints on nonporous media. However, latent prints of pre-pubescent children have been more difficult to develop as the prints age than the prints of adults.

A study was designed and executed to determine the efficacy of an acetic acid treatment, when combined with fuming at high relative humidity, in regenerating fingerprints. Acetic acid treatment was found to improve print quality in 18.8% of 250 sample pairs. The treatment was significantly more effective at improving the quality of clean prints than oily prints. Additionally, a significantly higher proportion of samples under fluorescent light and simulated sunlight were able to maintain their level of print quality as opposed to samples stored in the dark. The acetic acid treatment was also linked to reduced levels of background polymerization of aged samples regardless of print type or lighting condition.

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This research was performed while on appointment as a U.S. Department of Homeland Security (DHS) Fellow under the DHS Scholarship and Fellowship Program, a program administered by the Oak Ridge Institute for Science and Education (ORISE) for DHS through an interagency agreement with the U.S. Department of Energy (DOE). ORISE is managed by Oak Ridge Associated Universities under DOE contract number DE-AC05-00OR22750. All opinions expressed in this paper are the author's and do not necessarily reflect the policies and views of DHS, DOE, ORNL, or ORISE.

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Chapter 1

INTRODUCTION

Within a four-month span of time in 1993, Knoxville (TN) Police Department criminologist Art Bohanan was faced with two child abduction cases in which detection of the children's prints in the cars of the alleged abductors was essential to prosecution [*1*,*2*]. The car involved in the first case was processed four days after the kidnapping. Powder dusting, although generally considered one of the least sensitive fingerprint development techniques, is routinely used on prints up to one-week-old and has even been shown to develop prints as old as nine months [*3*,*4*]. However, although several people witnessed the young girl entering the car, no prints from the victim were found. Bohanan suspected the explanation was that "the child's fingerprints just weren't lasting very long" [*1*], and he resolved to press for processing of evidence as soon as possible in any future child abduction cases. Less than four months later, another young girl was abducted. The suspect's vehicle was found seven hours after the three-year-old victim's disappearance, and Bohanan made fingerprint processing a priority. Within thirty minutes, palm prints belonging to the child were located on the inside surfaces of the back windows. When the defendant recanted his confession (made while he was under the influence of drugs and alcohol) to the abduction, rape, and murder of the child, the recovered palm prints became even more important to the prosecution and eventual conviction of the defendant.

Intrigued by the implication of the casework, Bohanan searched for information on the differences between prints deposited by adults and children, but found no relevant reports [*1*]. Dissatisfied, Bohanan devised his own experiments to investigate the durability of children's prints. In one field test, Bohanan supervised children touching the insides of all the cars in police custody. Twenty-four hours later, no prints were detected. In another experiment, Bohanan directed adults and children to handle separate clean plastic and glass bottles. When he examined bottles stored inside vehicles, he found that the children's prints were often undetectable by powder after twenty-four hours, while adult prints could be recovered several days after deposition.

Interested in determining the reason for this difference in the limits of detection of prints deposited by children and adults, Bohanan approached scientists at Oak Ridge National Laboratory (ORNL). Dr. Michelle Buchanan, an analytical chemist, directed a study of the chemical composition of fingertip secretion samples from twenty-five children (from 4 to 12 years old) and twenty-five adults (from 17 to 64 years old). The secretions were extracted directly from the fingertip through contact with rubbing alcohol (70% v/v isopropanol in water). Analysis of the samples by gas chromatography/mass spectrometry (GC/MS) revealed a marked difference in the chemical composition of samples from the two different age groups [*1*]. Free fatty acids were found in greater abundance in the samples from children than in those from adults. Conversely, long-chain alkyl esters were found in much higher concentrations in the adult samples than in the samples from children. Free fatty acids are relatively small and volatile, while the long-chain alkyl esters are of a much higher molecular weight and less volatile. Thus, compositional differences translate into faster evaporation rates for children's prints than

adult prints. This in turn helps to explain why police have a much smaller window of time to detect children's prints.

GLAND SECRETIONS AND LATENT PRINT FORMATION

The human body contains three major types of secretory glands: eccrine, sebaceous, and apocrine. Eccrine glands are distributed throughout the surface of the body, with highest concentrations on the palms and the soles of the feet (together called the volar surfaces). Sebaceous glands are associated with hair follicles and are located throughout most of the body, particularly the face and scalp. Notable exceptions are the volar surfaces, which contain no hairs and therefore no sebaceous glands. However, secretions of the sebaceous glands (called sebum) are often found on volar surfaces, especially fingers and palms, due to frequent contact with other areas of the body like the face. Apocrine glands are localized to hair follicles in the axillary regions (that is, the armpits and genital area), and apocrine secretions rarely contact volar surfaces.

In addition to containing a high density of eccrine glands and no hair follicles or accompanying sebaceous glands, the volar surfaces are notable for the ridges of the skin. Designed to allow humans to grip objects, the skin ridges form intricate patterns that are considered unique to each individual. The latent (hidden) prints of interest to forensic scientists form when an area of this ridged skin, coated in eccrine secretions and/or transferred sebum, touches another surface. If the ridged skin (also called friction skin) is coated only in eccrine material, the deposited print is referred to as a "clean" print. If the friction skin has contacted non-volar surfaces, the deposited print is termed "oily"

because it contains a mixture of eccrine and sebaceous secretions.

Eccrine secretions are predominantly water (in excess of 98%), with traces of salts (most notably sodium chloride and sodium lactate), free amino acids, urea, mucoproteins, ammonia, and negligible amounts of lipid material [*5,6*]. In general, sebum is composed of triglycerides, wax esters, free fatty acids, squalene, sterols, and sterol esters [*5,6*]. The relative amounts of each component vary with respect to age, as discussed earlier, and also across individuals within the same age group. A major factor in the compositional disparity between secretions of adults and children appears to be the production of adrenal androgens, a process that begins between the ages of seven and ten. Sebaceous glands are underdeveloped in young children and epidermal lipids, such as cholesterol and cholesterol esters, dominate the sebum [*7*]; after adrenal androgens are produced, sebaceous lipids, such as squalene and wax esters, are prevalent at levels two to three times larger than during early childhood [*5,7*]. Additionally, free fatty acids form a larger percentage of the sebaceous material of children than of adults [*5*]. With more volatile components and smaller quantities of hygroscopic components, the prints of pre-pubescent children dry out more quickly than those of adults, provided that the fingers of the children are not contaminated with transfer sebum from an adult. The degree of evaporation of a print has important implications on the ability of many fingerprint development techniques, including cyanoacrylate fuming, to develop prints of good quality.

While the donor age dependency of the chemical content of general sweat samples has been well-established for decades [*5*], it was not until the work of Dr. Buchanan's group at ORNL that age-related compositional differences specific to

fingertip secretions were investigated and reported. A later study conducted at Pacific Northwest National Laboratory (PNNL) took the next step. Based on analysis of prints left on glass fiber filter paper [*8*], chosen as a neutral substrate that was practical for the subsequent analysis protocol, the PNNL study concluded that the compositional differences were detectable in the deposited prints of children and adults.

SUMMARY OF FINGERPRINT FORMATION AND DETECTION

The value of a fingerprint lies in its designation as individualizing evidence; that is, it is possible to identify the origin of a fingerprint as one, and only one, source. The single most important factor affecting a print examiner's ability to classify and individualize a print is print clarity. The options available to an examiner to maximize the clarity of a given print depend on how that print was produced. When a finger is pressed into a moldable substance (e.g. wax, caulk, or gum), the resulting three-dimensional reverse molding of the friction ridges and furrows is said to be an impressed print. Enhancement of impressed prints is typically limited to altering lighting conditions to increase the contrast between the ridges and furrows during photography of the print.

Prints formed by the transfer to the touched surface of a substance coating the friction ridges *other* than natural gland secretions (e.g. blood, ink, dirt) are called patent (visible) prints. Print clarity sometimes may be enhanced by lifting the print with transparent tape and transferring it to a background of greater contrast. Optical methods are often employed to enhance contrast of the print media and background substrate. Additionally, various chemical reagents have been developed to enhance weak prints

deposited in blood by targeting hemoglobin (e.g. tetramethylbenzidine, phenolphthalein, leucomalachite green) or proteins (e.g. amido black, ninhydrin, Coomassie blue, 1,8-diazafluoren-9-one, commonly known as DFO).

The third and most common method of print formation is by the transfer to the touched surface of natural gland secretions coating the friction ridges. Because the natural gland secretions are essentially colorless, such prints are not readily visible; hence, they are called latent (hidden) prints. A significant amount of scientific research has been conducted to successfully visualize latent prints with ever-improved clarity on a wider variety of substrates under a greater variety of conditions. Out of this research, numerous optical, physical, chemical, and (recently) instrumental methods have been established for the visualization of prints under specific conditions

OVERVIEW OF CYANOACRYLATE FUMING

Cyanoacrylate fuming, also known as Super Glue® fuming, is a chemical method of fingerprint development that has risen to prominence in recent years. It involves the vaporization and polymerization of liquid cyanoacrylate ester along the ridges of exposed fingerprints to yield a hard, white-colored print. The technique is most useful on nonporous surfaces such as plastics, metals, and glass. It is also routinely used on semiporous surfaces like rubber and glossy paper. In fact, cyanoacrylate fuming is the third technique (following standard visual examination and attempts at revealing inherent fluorescence by laser or alternate light source) employed by the FBI's Latent Print Unit on nonporous surfaces, the non-adhesive side of tapes, the semiporous paper side of

photographs, and semiporous glossy papers [9]. Cyanoacrylate fuming also appears in the FBI's recommended processing sequences for nonporous blood-stained specimens, semiporous rubber, and the emulsion side of photographs [9].

The compatibility of this technique with a large number of surfaces is one of its most notable advantages. Other advantages include the permanence of the developed prints; the simplicity of the procedure; the lack of damage to the fumed substrate; the ability to process many items of evidence simultaneously in the lab; the adaptability of the technique to field use; the ability to perform subsequent DNA testing on fumed fingerprint material; and the relatively low cost of the technique. Of course, cyanoacrylate fuming is not without disadvantages such as the danger of releasing cyanide gas at high fuming temperatures; the possibility of over-developing a print (i.e. substantial background polymer growth, particularly in the furrows between fingerprint ridges); and the poor contrast of developed prints with light-colored backgrounds. However, research has found ways around these pitfalls.

THE EVOLUTION OF CYANOACRYLATE FUMING RESEARCH

This technique originated in 1978 at the Criminal Identification Division of the Japanese National Police Agency [5]. However, it was not until workers from the U.S. Army Criminal Investigation Laboratory in Japan (USACIL-Pacific) and the Bureau of Alcohol, Tobacco, and Firearms introduced the technique to the United States in 1982 that scientists began researching ways to improve its efficiency and range of use [5].

The original procedure involved placing several drops of liquid cyanoacrylate

ester in a dish at the bottom of an enclosed container in which a specimen was suspended. Over the course of several hours at ambient conditions, the liquid cyanoacrylate vaporized and selectively polymerized along the ridges of any exposed fingerprints, producing durable whitish-colored prints. Figure 1 shows the structure and polymerization mechanism of the cyanoacrylate ester, where A^- represents an initiator (discussed in greater detail beginning on page 11) of the polymerization reaction, and R represents an alkyl group (commonly an ethyl group for cyanoacrylate fingerprint development).

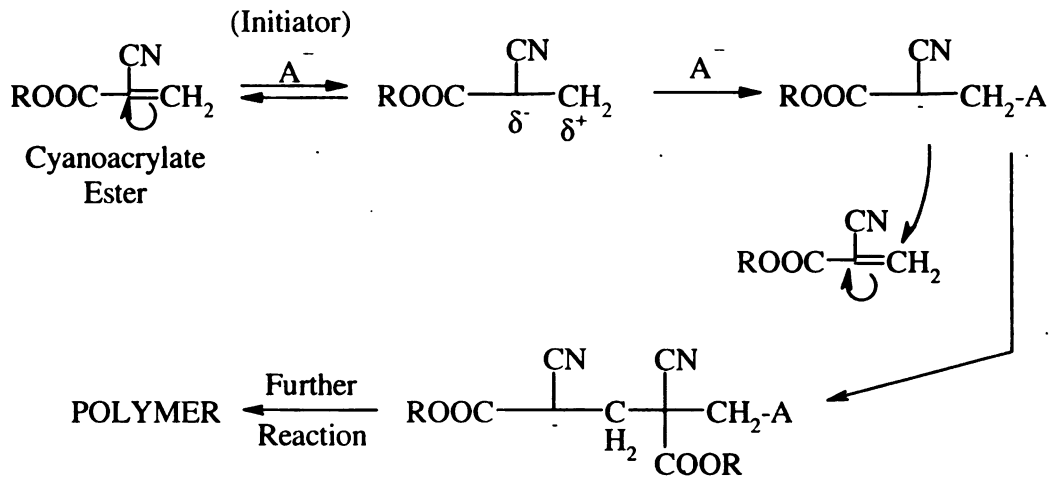

Figure 1: Cyanoacrylate Polymerization Mechanism

Soon, numerous articles were published describing procedures to accelerate the process, focusing on ways to increase the speed at which cyanoacrylate vapors were produced and/or improve the contact of cyanoacrylate fumes with the specimens. These first acceleration procedures included circulating the fumes with a small fan, heating the cyanoacrylate ester, and introducing the cyanoacrylate ester to the enclosure on absorbent cotton containing sodium hydroxide [5]. Current incarnations of the cyanoacrylate fuming procedure may incorporate one or more of these acceleration techniques.

However, these accelerated processes still typically require 30 to 60 minutes of fuming.

In 1986, Almog and Gabay reported a method that involved heating polycyanoacrylate, the solid polymeric form of cyanoacrylate [*10*]. In spite of the elimination of the risks associated with handling liquid cyanoacrylate, and a reduction of the fuming time to "a few minutes," the use of liquid cyanoacrylate still predominates. However, the method is sometimes adapted as a remedy to the problem of over-developed prints: careful heating of such prints can release monomeric vapors from the solid polymer. The drawback is that re-fuming of the print in question is not possible after such treatment [*5*].

A modification that *has* gained popularity is the use of a vacuum chamber to conduct the fuming at significantly reduced pressure. First presented in 1994, the vacuum procedure has two notable advantages over fuming at ambient pressure: the vacuum method is able to consistently develop high-quality prints on irregular surfaces, and the issue of over-fuming is significantly reduced. Unfortunately, vacuum fuming requires a relatively long fuming time and yields prints that have less cyanoacrylate build-up, making them harder to see and less robust than counterparts fumed at ambient pressure. Grady was able to significantly reduce the fuming time (as short as 12 minutes) by incorporating the heating of the cyanoacrylate, but difficulty with print visualization remained [*11*].

An alternate modification is the introduction of a source of humidity to the enclosure during the fuming process. The humidity source can be as simple as a cup of hot water or as sophisticated as a purpose-built humidity cabinet. Several references suggest achieving 80% relative humidity for optimal results [*6,12*]; however, the FBI

recommends fuming between 70% and 80% relative humidity [*9*], and a recent study maintained that a 60% relative humidity level produced the best quality prints [*13*].

With the "microburst" method of fuming conducted by the FBI using cyanoacrylate heated to approximately 400°C, fuming time has been pushed to between 30 seconds and four minutes [*9*]. Therefore, the focus of the majority of recent cyanoacrylate fuming research has shifted from acceleration to visualization enhancement.

One of the major disadvantages plaguing cyanoacrylate fuming is the lack of contrast of developed prints on light-colored backgrounds. A wide variety of post-fuming treatments have been reported to overcome this issue. A sampling of such treatments includes: dusting with standard, magnetic, or fluorescent fingerprint powders [*5,14*]; a combination of ninhydrin and zinc chloride followed by laser examination [*15*]; biological stains or Rit® fabric dyes [*16*]; europium-based fluorescent dyes [*17*]; sublimation dyes from the anthraquinone family of compounds that target the cyanoacrylate polymer [*18*]; sublimation-grade disperse dyes that target the background [*19*]. Visualization can also be improved by analyzing fumed prints with more sophisticated instrumentation. A recently published study employed a Fourier Transform Infrared (FTIR) spectrometer and infrared microscope to chemically image cyanoacrylate-fumed prints against the multi-colored background of the new Australian polymer banknote [*20*].

Improving the detection sensitivity (i.e. number and quality of developed prints) inherent to the cyanoacrylate fuming method itself is a valuable but less common area of research. Noting that amine vapors have been used in semi-conductor production to

activate inert surfaces for uniform cyanoacrylate polymer deposition, Burns *et al.* investigated the effect of ammonia exposure on the quality of developed prints [*21*]. The authors found that greater polymer deposition was achieved by exposing prints to ammonia vapors prior to cyanoacrylate fuming. However, they conceded that "the greatest polymer deposition does not always lead to the best visual mark. It is found that polymer deposits on the ridges up to a maximum point and then starts to deposit in the troughs of the fingerprint leading to a loss of detail [*21*]."

FUNDAMENTAL CYANOACRYLATE RESEARCH AT ORNL AND UT

Most of the research on cyanoacrylate fuming has been predicated on the assumption that the findings of the adhesives industry hold true for fingerprint development. One such fundamental finding is that the polymerization of cyanoacrylate ester is initiated by basic compounds, residual moisture, and trace metals [*21*]. In the late 1990s, researchers at Oak Ridge National Laboratory and the University of Tennessee (UT) collaborated on a series of experiments designed to elucidate the fundamental processes of cyanoacrylate polymerization as it applies to the forensic science community. They hoped that a more thorough understanding of the polymerization process would allow them to devise a means of improving the sensitivity of cyanoacrylate fuming to aged prints of both adults and children.

To date, unpublished work by Steve Wargacki and Dr. Mark Dadmun of UT demonstrated that both water and anionic compounds found in eccrine secretions (specifically lactate and alanine) initiate the polymerization of cyanoacrylate ester.

However, measurements of total polymer mass were greater for lactate- and alanine-initiated samples than for water-initiated polymerization, meaning anionic compounds are more effective initiators than water. When trials were conducted using separate solutions of lactate and alanine at basic, neutral, and acidic pH levels, the basic solutions yielded noticeably greater polymer mass totals than their neutral and acidic counterparts (which provided roughly similar polymer mass measurements). When the average molecular weights of polymer chains were compared, polymer chains formed by anions in basic and neutral conditions were found to have substantially greater molecular weights than those formed by pure water or anions in acidic conditions. Researchers concluded that water yields a small number of low molecular weight oligomers, acidic solutions of anionic initiators form a larger amount of low molecular weight polymers, and neutral and basic solutions of the anionic initiators form a smaller number of higher molecular weight polymers. Furthermore, researchers suspected that H^+ played a role in early termination of the cyanoacrylate polymerization reaction.

In aging studies conducted by ORNL researchers, cyanoacrylate fuming (at a relatively high ambient humidity) of oily adult depositions that were aged several months yielded prints that, though noticeably degraded, still contained some areas of adequate definition. However, fuming of eccrine-only adult depositions produced only faint traces of visible polymer after merely two weeks of aging [*6*]. While tests of individual sebum components confirmed that they are not involved in the initiation of the polymerization reaction [*22*], the results of the aging studies suggested that sebaceous materials do play some role in polymer growth. Scanning electron microscopy (SEM) images revealed a correlation between print composition and the morphology of the growing polymer:

eccrine-only prints support growth of a noodle-type structure, whereas oily prints (containing both eccrine and sebaceous components) support capsule-type formations that suggest an emulsification function for the sebaceous materials [*6*]. Together, the results of the initiation and aging studies suggest that the increased likelihood of developing an aged (that is, dried out) latent print at higher humidity has more to do with the ability of the added moisture to solubilize the eccrine-based anionic initiators than with direct initiation of the polymerization by the water.

Faced with poor results when cyanoacrylate is used on child depositions and aged adult depositions, researchers attempted to regenerate optimal print conditions by re-hydrating the prints prior to fuming [*22*]. They evaluated water and several weak acids (formic acid, propionic acid, isobutyric acid, valeric acid, vinegar, and glacial acetic acid) as regenerating agents and determined that glacial acetic acid provided the best results. Exposure to acetic acid prior to cyanoacrylate fuming was found to consistently regenerate clean prints from adults that had been aged up to five months, resulting in a quality of developed print that was equivalent to the quality of fresh (i.e. non-aged) prints. Lacking the hygroscopic sebaceous materials that are present in the oily prints of adults, children's prints are compositionally similar to the clean prints of adults. As such, researchers reasoned that children's prints should respond as favorably as clean adult prints to the acetic acid exposure. Indeed, this was the case during initial tests of prints from children. However, a subsequent large-scale study of children's prints recorded no meaningful improvement in the quality of prints developed with the regeneration treatment as compared to control prints that did not receive the regeneration treatment.

While reviewing the data, researchers realized that the trials with adult prints were

conducted in the spring, when ambient indoor relative humidity levels were approximately 75%. The study of children's prints, on the other hand, was conducted in the winter with ambient indoor relative humidity readings of approximately 25%. To determine if the difference in relative humidity could be responsible for the disappointing results in the children's study, two child prints that had aged eight months were fumed under high relative humidity conditions in the summer, one without the acetic acid treatment and the other with the treatment. In the demonstration, the quality of the treated print was clearly superior to the quality of the untreated print. Based on this demonstration, and the results of the initial trials, the ORNL researchers deduced that humidity conditions within the fuming chamber have a crucial effect on the quality of developed prints.

In an attempt to substantiate the favorable results that had been obtained during the initial trials of children's prints and the demonstration, the author of this thesis designed and executed a study of prints deposited by 25 two- to five-year-old children. The previous children's print study [22] was used as a model, but the present study included several significant changes. Most notably, all fuming was conducted at high humidity. Additionally, the regeneration treatment was substantially modified such that acetic acid exposure and cyanoacrylate fuming were incorporated into a one-step print development method. Finally, a third lighting option was evaluated. Lactate, a main initiator of the polymerization process, is known to undergo photodegradation. The sample size of this study was deemed large enough to accommodate investigation of the effect of sample aging under sunlight, in addition to fluorescent lighting and darkness. Exposure to continuous natural sunlight was impossible, so simulated sunlight was used.

Chapter 2

MATERIALS AND METHODS

PROTOCOL DEVELOPMENT / OPTIMIZATION STUDIES

For the initial investigations into optimal fuming parameters, clean adult prints were used in place of children's prints. Latent prints were placed on clean glass microscope slides. Clean adult prints (composed of eccrine material only) were prepared as follows: hands were thoroughly washed and rinsed; palms were swabbed with an ethanol-soaked wipe; hands were air-dried; thumb and forefinger were rubbed together to create an even coating of eccrine material; and thumbs were firmly pressed on the glass slides. Oily adult prints (composed of both eccrine and sebaceous material) were prepared in a similar manner, except once hands were dry, the thumb was swiped across an oily region of the face (the side of the nose) before deposition on the glass slides. The prints were stored in the dark in a laboratory drawer for periods of time up to seventeen days.

The fuming chamber (Figure 2 on the following page) was constructed from a thick-walled Plexiglas box with internal dimensions measuring 30.1 cm (length) x 30.1 cm (width) x 31.0 cm (height). The bottom of the box was removed, and the box was placed on a metal platform with a square hole (14.0 cm x 15.9 cm) cut out of the center. A hotplate (Ceramag Midi IKA Works Inc., Wilmington, NC) was positioned within this

hole so its surface was level with the platform. A T-shape connector was used to direct both a stream of air and the output from a PUM100 Bionaire Humidifier (SIRCHIE Fingerprint Labs, Youngsville, NC) through tubing that was inserted into a 1-inch-diameter hole in the wall of the fuming chamber. The flow rate of the stream of air was monitored by an airflow meter (Dwyer Instruments Inc., Michigan City, IN) placed before the T-shape connector. The voltage supplied to the humidifier was controlled by a VARIAC variable autotransformer (Technipower LLC, Danbury, CT).

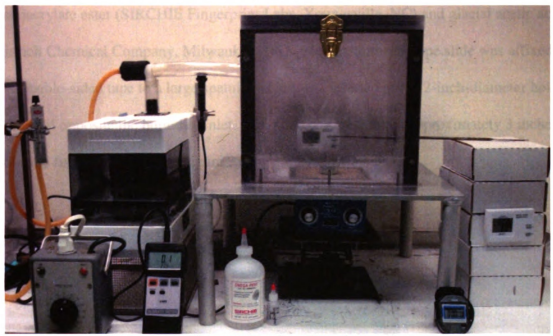

Figure 2: Fuming Chamber
(Images in this thesis are presented in color.)

A digital hygro-thermometer (Control Company, Friendswood, TX) was mounted to the back wall of the fuming chamber approximately 3 inches from the bottom. Faced with some discrepancy within the literature on the relative humidity level that achieves optimal fuming results [*6,9,12,13*], FBI recommendations to fume between 70% and 80% humidity were followed, with the range restricted to its lower half based upon the

influence of recent findings that advocated lower relative humidity levels for best results [*13*]. To achieve this targeted relative humidity range (70% - 75%) within the fuming chamber, the humidifier was set on operating level 2, the VARIAC was set at approximately 70V, and the airflow was regulated to 10 L/min. Once the humidity reading reached an appropriate level, an aluminum dish (VWR Scientific Products, West Chester, PA) containing the fuming compound was positioned on the hotplate which was heated to a surface temperature of 150°C. Fuming compounds included ethyl-2-cyanoacrylate ester (SIRCHIE Fingerprint Labs, Youngsville, NC) and glacial acetic acid (Aldrich Chemical Company, Milwaukee, WI). The glass microscope slide was affixed with double-sided tape to a large spatula, which was inserted into a 2-inch-diameter hole in the wall opposite the humidity inlet. The slide was positioned approximately 3 inches above the fuming compound (Figure 3).

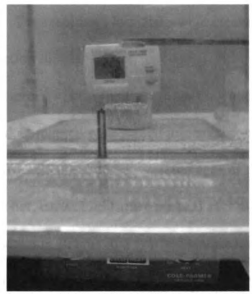

Figure 3: Sample Position Within Fuming Chamber
(Images in this thesis are presented in color.)

Throughout the optimization trials, the amounts and sequences of the fuming

compounds were varied, as were fuming times. (Relevant details about these variations are provided in the Results and Discussion section of this thesis.) The finalized protocol for the regeneration treatment called for 90 seconds of fuming using approximately 0.36g of a 2:1 (w:w) cyanoacrylate:acetic acid mixture.

PREPARATION OF CHILDREN'S PRINTS

Approval to conduct research involving human subjects was obtained from the Oak Ridge Site-wide Institutional Review Board and the Michigan State University Committee on Research Involving Human Subjects.

One-inch diameter mirrored glass disks (Darice Inc., Strongville, OH) were soaked in 70% nitric acid (Mallinckrodt Laboratory Chemicals, Phillipsburg, NJ) to remove the silver backing. The resulting glass disks were cleaned, dried, and affixed to the bottom of plastic collection dishes.

A local pre-school agreed to host the fingerprint collection activity. Parental consent was obtained and documented with signed informed consent forms. A total of 500 prints were collected from 25 children between the ages of two and five years. Guided by a gloved researcher, each child firmly pressed each finger against a separate clean glass disk for three seconds. Each child washed his/her hands with soap and water, allowed them to air-dry, and then repeated the print collection procedure. (Thus, each child deposited twenty total prints.) Each child was assigned a participant number, which was recorded along with the child's age and gender (but not the child's name). Each collection dish was labeled with the child's participant number, a code letter representing

which of the child's ten digits produced the print, and the word "before" (for oily prints deposited prior to hand-washing) or "after" (for clean prints deposited after hand-washing). The code letter assignments are summarized in Table 1.

Table 1: Letter Codes Used to Represent Each Finger

Code Letter	Hand	Finger
a	Left	Thumb
b	Left	Index Finger
c	Left	Middle Finger
d	Left	Fourth Finger
e	Left	Little Finger
f	Right	Thumb
g	Right	Index Finger
h	Right	Middle Finger
i	Right	Fourth Finger
j	Right	Little Finger

All prints were transported to the lab and stored in the dark while a storage plan was created specific to the overall study size and the age and gender distribution of the participants. For a list of the gender and age of each participant, see Appendix A (page 57). The storage plan divided the total number of collected prints into 25 sample sets. Each sample set contained a pair of clean prints (those collected after hand-washing) from the same digit of both hands of five different children, as well as a pair of oily prints (those collected before hand-washing) from the same digit of both hands of another five children. Thus, each sample set contained pairs of prints from 10 different participants. This was done to prevent the possibility of skewed data for any sample set due to the inherent inferior print quality of a single participant. Print quality can be affected by factors particular to individuals such as skin conditions and secretion amounts; therefore, some people consistently deposit poorer quality prints than others. The left-hand print (labeled a-e) of each pair was designated for development by cyanoacrylate fuming at

high humidity *without* the acetic acid regeneration treatment; the right-hand print (labeled f-j) of each pair was designated for development by cyanoacrylate fuming at high humidity *with* the acetic acid regeneration treatment.

Reflecting the gender ratio of the overall population, three of the pairs of clean prints and three of the pairs of oily prints in each sample set belonged to female participants, while two pairs of clean prints and two pairs of oily prints had been deposited by male participants. Attempts were also made to reflect the overall age distribution within sample sets. Table 2 provides an illustration of these assignments using the 20 individual samples assigned to Sample Set #1.

Table 2: The 20 Individual Samples Assigned to Sample Set #1

Participant #	Participant Gender	Participant Age	Finger Code	Designated for Acetic Acid?	Print Type
1	F	5	a	No	Clean
5	F	4	b	No	Clean
18	F	3	c	No	Clean
4	M	5	d	No	Clean
6	M	5	e	No	Clean
2	F	5	a	No	Oily
13	F	4	b	No	Oily
19	F	3	c	No	Oily
8	M	5	d	No	Oily
20	M	3	e	No	Oily
1	F	5	f	Yes	Clean
5	F	4	g	Yes	Clean
18	F	3	h	Yes	Clean
4	M	5	i	Yes	Clean
6	M	5	j	Yes	Clean
2	F	5	f	Yes	Oily
13	F	4	g	Yes	Oily
19	F	3	h	Yes	Oily
8	M	5	i	Yes	Oily
20	M	3	j	Yes	Oily

CYANOACRYLATE FUMING OF CHILDREN'S PRINTS

Sample Set #1 was pulled aside for immediate fuming; the remaining 24 sample sets were divided equally among three storage conditions. Eight of the sample sets were stored in the dark inside a laboratory cabinet. Eight of the sample sets were stored under continuous fluorescent illumination, approximately 22 inches below two 18-inch, 15-watt F15T8-WW Warm White fluorescent bulbs (General Electric Company, Cleveland, OH) with spectral distribution from 380 nm to 730 nm (primary peaks at 530-540 nm and 580-600 nm). The final eight sample sets were stored under continuous "simulated sunlight" illumination, approximately 22 inches below two 18-inch, 15-watt F15T8 Natural Sunlight bulbs (Philips Lighting Company, Somerset, NJ) with spectral distribution from 360 nm to 738 nm (primary peak at 444 nm). The specific storage plan used in this study is summarized in Appendix A (page 58).

After designated aging times, specified sample sets were removed from storage conditions and fumed. The choice of aging times under investigation was limited by the number of available sample sets. The samples sets kept in the dark were fumed after 2, 3, 4, 5, 7, 14, 21, and 28 days of storage. Three of the sample sets under fluorescent and "simulated sunlight" illumination were fumed within one day of storage (at 1.5 hrs, 3 hrs, and 18 hrs). These early fumings of illuminated samples were completed because a previous study [22] had concluded that lactate photodegradation, a major contributor to poor print development, occurs rapidly. The remaining five samples sets subjected to each type of illumination were fumed after 2, 3, 4, 5, and 7 days of storage. All sample sets were fumed with the humidifier operating at setting '2' and an airflow rate of 10 L/min. However, three different VARIAC settings were employed over the course of the

study. Sample Set #1 (the initial fuming) was developed with the VARIAC supplying 85V to the humidifier. Sample Sets #2-6 (the sets under illumination for less than one day) were developed with the VARIAC supplying 70V to the humidifier. Sample Sets #7-25 (all sets in dark storage and those sets under illumination for two or more days) were developed with the VARIAC supplying 75V to the humidifier.

Prints not receiving the regeneration treatment were fumed using approximately 0.24 g of ethyl-2-cyanoacrylate ester in an aluminum dish placed on a hotplate heated to a surface temperature of 150°C. Prints were initially exposed to fumes for 30 seconds; additional fuming time was added for visibly underdeveloped prints in 30-second increments up to a maximum total fuming time of 120 seconds.

Treated prints were fumed using approximately 0.36 g of a 2:1 (w:w) ethyl-2-cyanoacrylate ester:glacial acetic acid mixture. Prints were initially exposed to fumes for 90 seconds; additional fuming time was added for visibly underdeveloped prints in 30-second increments up to a maximum total fuming time of 180 seconds. The fuming time, temperature within the chamber, and humidity level within the chamber were recorded for all prints.

Once the fuming of all sample sets was completed, a visual examination of each print was conducted under ambient room lighting. Each print was assigned a rating for the overall print quality ("good," "fair," "poor," or "X" for undeveloped prints). Essentially, print quality is analogous to the clarity and quantity of ridge detail. To receive a quality rating of "good," a print had to have a substantial area of well-defined ridge detail. That is, several Level 2 ridge details (also called minutiae) used by trained print examiners to make print identifications, such as ridge endings and bifurcations

(forkings), had to be discernible. A rating of "fair" was assigned to prints having only limited Level 2 ridge detail, either because the area of adequate clarity was small, or because the ridge detail was difficult to visualize. The "poor" rating was assigned to prints with no visible minutiae. In addition to overall print quality, a rating was assigned to indicate the amount of background development ("none," "low," "medium," or "high").

Digital images were obtained using a Panasonic Color Digital Camera GP-KR22 with Navitar 7000 Zoom lens (Figure 4) and Interface Industrial Image capture board equipped with Oculus TCiPro Version 2.20 imaging software (Coreco Inc., Saint-Laurent, Quebec, Canada). The glass disks were photographed against a black background with oblique lighting from a Fiber-Lite High Intensity Illuminator (Dolan-Jenner Industries Inc., Lawrence, MA). The two light sources of the dual gooseneck illuminator were positioned on opposite sides of the disk (Figure 5, following page), at distances of between 1.5 and 3.5 inches.

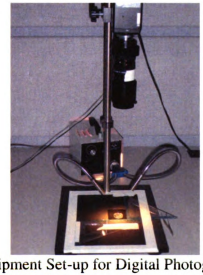

Figure 4: Equipment Set-up for Digital Photography of Prints
(Images in this thesis are presented in color.)

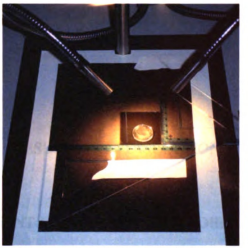

Figure 5: Sample Illumination During Digital Photography of Prints
(Images in this thesis are presented in color.)

Chapter 3

RESULTS AND DISCUSSION

PROTOCOL DEVELOPMENT / OPTIMIZATION STUDIES

Clean adult prints were used as a substitute for child prints while the optimal fuming parameters were investigated. During the trials, slight adjustments were made to the voltage setting of the VARIAC to maintain the target relative humidity level. Increasing the voltage setting would increase the output from the humidifier and raise the humidity level in the fuming chamber; conversely, decreasing the voltage setting would decrease the humidifier output and subsequently lower the humidity level in the fuming chamber. The targeted humidity level range was 70-75%. Because the fuming chamber was open to the surrounding environment by way of the sample insertion port, precise control and maintenance of the humidity measurement was limited. In practice, anything between 68% and 78% was considered acceptable.

The first parameter of interest was the amount of acetic acid exposure necessary for developing prints of good quality. Prints developed by cyanoacrylate fuming at high humidity without any exposure to acetic acid served as controls. In previous work with the acetic acid regeneration treatment [22], samples were "slightly fogged" with heated acetic acid vapors three successive times, with time allowed for mist dissipation between each exposure. In the current study, this "slight fogging" was achieved by exposure to heated acetic acid for 5 seconds. In multiple trials of samples aged up to three days,

limiting acetic acid exposure to one 5-second fogging yielded developed prints of better quality than prints developed after three 5-second exposures to acetic acid. Prints treated in the latter manner had high levels of background development plus beading along the fingerprint ridges, which served to obscure ridge detail.

Another variation under investigation was fuming the samples in an environment of acetic acid vapors combined with high humidity. Acetic acid was heated for 3 to 4 minutes to allow the vapors to saturate the fuming chamber. Then the dish of acetic acid was removed and replaced with a dish of cyanoacrylate. In multiple trials of samples aged up to three days, the prints developed in the acetic acid environment were faint (i.e. low polymer build-up along ridges) with moderate to substantial background development that obscured ridge detail. In trials that altered the amount of time acetic acid vapors were allowed saturate the chamber (approximately 2 minutes and 18 minutes), the subsequent development yielded substantial background that interfered with the ridge details. Thus, fuming in an acetic acid environment led to adverse results, and further work in this direction was abandoned.

A second major parameter of interest was the mass of cyanoacrylate necessary for good development of prints. Trials were conducted using fresh samples and samples aged 3 and 4 days. In the modified "microburst" method of fuming employed throughout this study, with samples fumed individually (or at most two-at-a-time) while held 3 inches directly above the heated cyanoacrylate, relatively small amounts of cyanoacrylate would be required. Therefore testing began with the smallest possible mass (one drop, average mass of 0.033g) and increased by whole number increments of drops. Less than 0.10g of cyanoacrylate (three drops) was unable to sustain vapor production for a length

of time necessary for adequate polymerization of the ridges, yielding faint underdeveloped prints. Samples fumed for 30 seconds with between 0.14g and 0.24g (four to seven drops) of cyanoacrylate yielded prints of adequate quality. Samples fumed for 30 seconds with 0.27g or more (eight or more drops) of cyanoacrylate yielded prints with high levels of interfering background development. In subsequent testing of 10-day-old oily adult prints, fuming with less than approximately 0.24g (seven drops) of cyanoacrylate yielded developed prints that could be smeared. Permanence of developed prints is a desirable advantage of cyanoacrylate fuming. Therefore, 0.24g (seven drops) of cyanoacrylate was chosen as the amount able to achieve the best development of both clean and oily prints under the given fuming conditions (i.e. samples of a small size positioned close to the source of the cyanoacrylate fumes).

The next important parameter to investigate was the method of acetic acid exposure. While good results were produced by earlier trials of sequential exposure to acetic acid and cyanoacrylate, a one-step simultaneous exposure to both compounds would simplify the process and make acetic acid regeneration more appealing to forensic scientists. Unfortunately, it was not possible to precisely measure the amount of acetic acid that vaporized in 5 seconds. Additionally, it was noted that there was typically a 5- to 10-second delay between the placement of the acetic acid on the hotplate and the introduction of the fingerprint sample into the humidity chamber. A starting volume of 0.1 mL of acetic acid was found to completely evaporate in an average of 45 seconds, well surpassing the total 10- to 15-second evaporation time that was estimated as necessary. However, in trials of simultaneous fuming by 0.1 mL acetic acid and approximately 0.24g (seven drops) of cyanoacrylate, the resulting prints were found to

have a print quality (i.e. clarity of ridge detail) analogous to those developed by the earlier runs of sequential fuming with only 5 seconds of acetic acid exposure. During simultaneous fuming, the production of visible cyanoacrylate fumes was delayed, and longer total fuming times were necessary to achieve the same print quality (105 seconds, as compared to the 30 seconds typically adequate during sequential fuming). However, it was suspected that some polymerization of the cyanoacrylate had begun before all the acetic acid had evaporated, thereby neutralizing the deleterious effects of using larger quantities of acetic acid (as demonstrated in the earliest sequential-fuming trials). The conditions for simultaneous fuming were repeated in numerous trials of prints aged up to 7 days; all trials yielded prints of good quality and clarity.

A volume of 0.1 mL acetic acid has a corresponding average mass of 0.105g; therefore, the initial mixture was roughly 20 parts (0.24g) cyanoacrylate to 9 parts (0.105g) acetic acid. Because the selection of 0.1 mL of acetic acid had been somewhat arbitrary, trials were conducted using mixtures with different ratios of the components. Using the 20:9 (or 10:4.5) initial ratio as a starting point, tested ratios included 10:4, 10:5, and 10:6 cyanoacrylate:acetic acid. As always, multiple trials were conducted on clean adult prints. The 10:5 mixture (or 2:1 mixture) yielded prints within 90 seconds of fuming that had the best combination of high ridge detail and low background. When tested on oily prints, the 2:1 mixture was found to be equally effective. Because the 2:1 mixture was bracketed on both sides (i.e. both more and less acetic acid content) by mixtures that performed worse, further ratio variation experiments were discontinued.

Thus, at the conclusion of the optimization trials, a method of administering the acetic acid regeneration treatment was available. When fumed at high humidity, samples

of clean and oily adult prints aged up to 17 days that were subjected to the regeneration treatment (consisting of approximately 0.35g of cyanoacrylate and acetic acid in a 2:1 (w:w) mixture) developed with comparatively greater print clarity and less background polymerization than samples fumed with the standard cyanoacrylate-only treatment. This refined acetic acid treatment method was next applied to the study of children's prints.

PREPARATION OF CHILDREN'S PRINTS

A total of 500 prints were collected from 25 children for use in this study. The population included 15 females and 10 males, and the ages of the participants ranged from two to five years. For a list of the gender and age of each study participant, see Appendix A (page 57). The prints were divided into 25 sample sets of 20 prints, as discussed in the Materials and Methods section of this thesis, and stored under one of three lighting conditions. Lewis *et al.* previously reported on the photodegradation of the lactate present in fingerprint material [22], a phenomena that occurs in prints exposed to sunlight as well as fluorescent lighting. Storage under natural sunlight was impractical due to the inability to maintain continuous lighting and the possibility of rain harming the fingerprint samples. Instead, sunlight was "simulated" using a specially-marketed light with a spectral distribution that penetrated further into the UV wavelengths than standard fluorescent lighting. The specific storage assignments are provided in Appendix A (page 58).

CYANOACRYLATE FUMING OF CHILDREN'S PRINTS

On the day that fuming was scheduled to begin, the hotplate used throughout the optimization trials (Ceramag Midi IKA Works Inc., Wilmington, NC) failed to heat. No hotplate with similar dimensions was available; therefore, the non-functioning hotplate was replaced with a larger one (Corning Inc., Acton, MA). Not able to fit within the metal platform's hole, the larger hotplate was positioned directly below the platform. To achieve the target humidity range (70% - 75%), the voltage output to the humidifier was increased to 85V.

The first set of 20 samples was fumed under the conditions described above. The majority of the samples (18 of 20) had little to no ridge detail. Two samples failed to develop any print detail at all, and only two samples received a "good" rating for the overall quality of the print development. In addition, 18 of the 20 samples had moderate or high levels of background polymerization. These results were unexpectedly poor given the relatively short time interval between deposition and development (the prints of Sample Set #1 were only subject to the day-long dark storage common to all samples while the detailed storage plan was created and the prints were sorted according to the plan). Also of note was the tendency of the polymer build-up to be easily brushed off the substrate surface. Together, these factors indicated that the relative humidity during fuming was too high.

When data was reviewed, it was realized that the temperature within the fuming chamber was more than 10 degrees higher than it had been during the optimization trials. The surface contact between the larger hotplate and the metal platform caused this elevation. Because humidity levels are relative to the temperature and volume of the air,

and the volume of air in the fuming chamber was fixed, more moisture output by the humidifier was required to maintain the target humidity readings at the higher temperatures. However, this increase in the total moisture content of the air hindered the efficacy of the cyanoacrylate fuming. During optimization trials, voltage settings between 70V and 75V had produced a moisture content in the fuming chamber effective at improving the quality of cyanoacrylate fuming results. Returning the voltage setting to 70V ensured that the same moisture content would be present, even though the relative humidity measurements would be lower than they had been during the optimization trials due to the increased temperature.

Another noteworthy issue from the initial fuming was that the fuming compounds (whether cyanoacrylate-only or the 2:1 (w:w) cyanoacrylate:acetic acid mixture) did not produce visible fumes as readily as they had in the optimization trials. Jostling the hotplate was found to aid in the timely production of such visible fumes. It is not understood why the difficulty arose, but the jostling motion was adopted during all subsequent fumings to overcome the issue.

The adjusted conditions (large hotplate; 70V voltage setting; jostling motion to increase fume production) were used to fume the next six sample sets, comprised of prints stored under fluorescent lighting or "simulated sunlight" for 1.5, 3, or 18 hours. Following these fumings, a smaller hotplate (Cole-Parmer Instrument Co., Vernon Hills, IL) was located. The hole in the platform was slightly widened to allow this newest hotplate to be raised into a position level with the bottom of the fuming chamber. Despite removing the direct hotplate-to-platform contact, temperatures within the fuming chamber remained elevated as compared to temperatures during the optimization trials

conducted with the first hotplate. The reason for this disparity remains unknown. The voltage setting was increased to 75V (the high end of the voltage range employed during the optimization trials), and all remaining sample sets were fumed under these adjusted conditions. A summary of storage and fuming conditions for all sample sets is presented in Appendix A (page 59).

Once all sample sets were fumed, the individual samples were examined visually under ambient room lighting. Each sample was assigned one of four overall print quality ratings ("good," "fair," "poor," or "X") based upon the clarity and quantity of ridge detail as previously described on pages 22 and 23. Development traits that impeded the clarity of a print included smearing, interference due to background polymerization (often hazy, sometimes spotty), faint polymer deposition along ridges (considered "underdeveloped" prints), indistinct ridges (presumably from excess pressure or slight shifting of fingers while laying down prints), and spotty polymer deposition along ridges (which permitted visualization of the general ridge pattern, but not of minutiae). The presence of these traits often led to "fair" or "poor" ratings, but a connection was not automatic; as long as several minutiae were visible, a print could receive a "good" rating despite having a negative characteristic such as an area of spotty development.

Examples of the four overall quality ratings are shown in Figure 6 (following page). Image 6A depicts a clean print from Participant #12 assigned a rating of "good." Note that the print appears as a reverse image of darker ridges against a white haze of background polymerization. Image 6B depicts an oily print from Participant #6 that also received a rating of "good." Image 6C presents a clean print from Participant #9 assigned a rating of "fair." Although the top of the print is not well developed, the bottom of the

print is clear enough to visualize some minutiae. Image 6D depicts a clean print from Participant #17 assigned a rating of "poor." Only a few short ridges developed distinctly, and no Level 2 ridge detail is visible. Image 6E presents an oily print from Participant #1 that also received a rating of "poor" because of the widespread discontinuities along the ridges. While Level 1 ridge detail (general print pattern) was visible, the numerous discontinuities prevented any Level 2 ridge detail from being seen. Image 6F shows an oily print deposited by Participant #18 that was assigned a rating of "X" because no development was visible after fuming. All prints in Figure 6 had been stored for 2 days under simulated sunlight prior to cyanoacrylate fuming with acetic acid treatment.

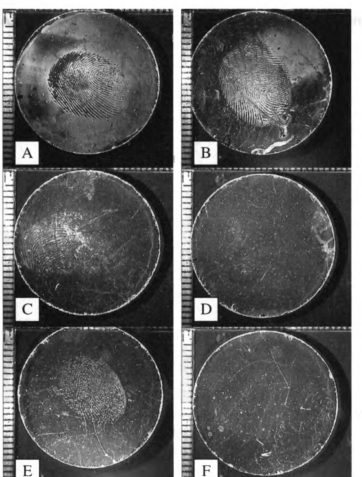

Figure 6: Examples of the Four Overall Print Quality Ratings – "good" (A & B), "fair" (C), "poor" (D & E), and "X" (F)
(Images in this thesis are presented in color.)

In addition to the print quality rating, each print was assigned a rating based on the relative amounts of background polymerization using the following scale: "none," "low," "medium," or "high." Examples of prints categorized as one of the four background polymerization ratings are shown in Figure 7. Image 7A depicts a clean print from Participant #11 fumed with acetic acid treatment, and assigned a rating of "none." Image 7B depicts an oily print from Participant #14 fumed without exposure to acetic acid, and assigned a rating of "low." Image 7C depicts a clean print from Participant #22 fumed with acetic acid treatment, and assigned a rating of "medium." Image 7D depicts a clean print from Participant #3 fumed without exposure to acetic acid, and assigned a rating of "high." All prints in Figure 7 were stored for 2 days under fluorescent lighting prior to cyanoacrylate fuming.

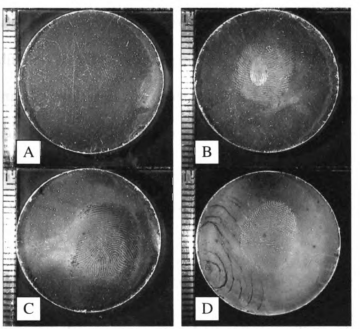

Figure 7: Examples of the Four Background Polymerization Ratings – "none" (A), "low" (B), "medium" (C), and "high" (D)
(Images in this thesis are presented in color.)

In addition to the print clarity and background polymerization ratings,

descriptions of the print appearance were recorded. The ratings were then analyzed to determine what influence, if any, each of the main experimental design parameters had on successful print development. These parameters included print type, lighting condition, aging time, and (most notably) treatment option.

General Print Type Effects

A combined 63% (199 + 116 = 315 out of 500) of all samples developed with "good" or "fair" overall print quality. Although quality rating percentages were not presented in the report of the previous children's print study [22], discussions with the authors of that report indicated that this present study's "success rate" was substantially improved over that of the previous study where the children's prints had been fumed at low relative humidity levels. When the samples were divided according to print type (Table 3), no statistically significant difference was found between clean and oily prints in any of the four quality ratings. The statistical test used on this data, and all subsequent data presented in this thesis, was the test of differences between proportions. A detailed explanation of this test can be found in Appendix B.

Table 3: Overall Print Quality Ratings According to Print Type (All Samples)

		500 **Total** Samples		250 Clean Samples		250 Oily Samples	
Overall Quality Ratings	good	199	(39.8%)	95	(38.0%)	104	(41.6%)
	fair	116	(23.2%)	58	(23.2%)	58	(23.2%)
	poor	174	(34.8%)	91	(36.4%)	83	(33.2%)
	X	11	(2.2%)	6	(2.4%)	5	(2.0%)

This result was unexpected. In past research on the acetic acid regeneration method, higher quality prints developed from oily deposits than from eccrine-only deposits [*6,22*]. One possible explanation for the deviation from this general trend relates to an unforeseen difficulty encountered during print collection. Although care was taken to standardize the print collection procedure as much as possible, researchers were not able to control all variables at the pre-school collection site. Notably, the print collection procedure was initiated after two participants had recently washed their hands. It was unknown whether or not the children had collected any oily residue through touch in the interim between their personal hand-washing and their participation in the print collection procedure. Therefore, the "before hand-washing" prints of these participants may or may not have contained oily components. Indeed, when the data was sorted according to participant, the "oily" prints of the two participants in question were assigned lower ratings than similarly labeled prints of other participants. The potential for skewed data exists if the same phenomena unknowingly occurred with additional participants.

A second explanation for the unexpected equivalency of oily and clean print quality ratings is that the benefits associated with fuming at high humidity may balance out the inherent differences between print types. In reviewing previous cyanoacrylate print development studies, it was discovered that the only studies that specifically mentioned using clean adult test prints or children's prints [*6,22*] did not control the humidity levels during cyanoacrylate fuming. Without a study of clean adult prints and/or children's prints fumed at high humidity to which the present study's results can be compared, it is unknown whether the observed similarity between clean and oily print quality ratings is due to high humidity alone, or the combination of high humidity and

acetic acid treatment.

Table 4: Background Polymerization Ratings According to Print Type (All Samples)

Bkgd Polymeriz. Ratings	500 **Total** Samples		250 Clean Samples		250 Oily Samples	
none	204	(40.8%)	77	(30.8%)	127	(50.8%)
low	165	(33.0%)	100	(40.0%)	65	(26.0%)
medium	71	(14.2%)	43	(17.2%)	28	(11.2%)
high	60	(12.0%)	30	(12.0%)	30	(12.0%)

When the background polymerization ratings were totaled (Table 4, above), 73.8% of all samples (204 + 165 = 369 out of 500) showed little or no polymerization on the glass background material. When the data were separated into two groups based on print type, statistically significant differences were found for both the "none" and the "low" ratings between the proportion of clean prints and the proportion of oily prints receiving each rating. However, because "low" levels of background polymerization rarely impinged on the more crucial evaluation of overall print quality, a consideration of greater relevance may be the combined total of the "low" and "none" ratings. When combined, the resulting proportions for clean and oily prints (70.8% and 76.8%, respectively) were not found to be significantly different.

Print type is essentially a description of print composition. The composition of the print was not expected to have any direct bearing on the degree of polymerization of the background material, which was reflected in the similarity of the combined values for the "low" and "none" ratings. However, print type/composition was seen to have a direct effect on fuming time. Namely, oily depositions generally required a shorter amount of

time to produce visible prints than their clean counterparts. The shorter exposure times to cyanoacrylate fumes of oily print samples account for the greater number of oily prints garnering a rating of "none" as compared to clean print samples.

General Lighting Condition Effects

Of the 500 total samples, 20 were fumed without storage (Sample Set #1) and the remaining samples were distributed evenly among the following three lighting conditions: dark storage, fluorescent lighting, and simulated sunlight. However, because samples from the three different lighting conditions were not always fumed at the same time (see the explanation on page 21), a comparison of the results from all 160 samples under each lighting condition could be misleading. To avoid misconstruing an aging effect as a lighting condition effect, only the samples fumed at aging durations common to all three lighting conditions (2, 3, 4, 5, and 7 days) were considered for analysis. When this restriction was imposed, no significant difference was found among any of the lighting conditions with respect to the overall print quality distribution (Table 5).

Table 5: Overall Print Quality Ratings According to Lighting Conditions (Samples Aged 2 to 7 Days)

		300 **Total** Samples aged 2-7 days		100 Dark Samples aged 2-7 days		100 Fluor. Samples aged 2-7 days		100 Sunlight" Sample aged 2-7 days	
Overall Quality Ratings	good	113	(37.7%)	37	(37.0%)	38	(38.0%)	38	(38.0%)
	fair	65	(21.7%)	21	(21.0%)	20	(20.0%)	24	(24.0%)
	poor	116	(38.7%)	40	(40.0%)	40	(40.0%)	36	(36.0%)
	X	6	(2.0%)	2	(2.0%)	2	(2.0%)	2	(2.0%)

The similarity in rating percentages of samples subjected to fluorescent lighting and simulated sunlight is not surprising. Although marketed as two very different lighting conditions, the bulbs used in this study emitted light with similar spectral distributions. However, the lack of significant difference between the samples stored in the dark with those stored under either form of illumination is of interest. Such results seem to contradict the expectation that prints stored in the dark, and therefore not subject to photodegradation of the main polymerization initiator (lactate) found in fingerprint depositions, would yield developed prints of higher quality. This indicates that either the lactate photodegradation was not substantial enough to become a major factor within the seven days that samples were subjected to continuous illumination, or that the fuming conditions employed in this study were able to compensate for any detrimental lactate photodegradation that did occur.

When background polymerization was considered in relation to lighting conditions for the restricted sample groups (Table 6), no significant differences were found among the three lighting conditions. Like overall print quality, background polymerization levels were not found to be linked to variation in the lighting conditions used in this study.

Table 6: Background Polymerization Ratings According to Lighting Conditions (Samples Aged 2 to 7 Days)

		300 **Total** Samples aged 2-7 days		100 Dark Samples aged 2-7 days		100 Fluor. Samples aged 2-7 days		100 Sunlight" Sample aged 2-7 days	
Bkgd Polymeriz. Ratings	none	149	(49.7%)	51	(51.0%)	49	(49.0%)	49	(49.0%)
	low	106	(35.3%)	39	(39.0%)	32	(32.0%)	35	(35.0%)
	medium	34	(11.3%)	9	(9.0%)	12	(12.0%)	13	(13.0%)
	high	11	(3.7%)	1	(1.0%)	7	(7.0%)	3	(3.0%)

General Aging Effects

Clean and oily prints were successfully developed at high humidity both with and without acetic acid treatment from 7-day-old samples stored under fluorescent lighting and simulated sunlight, and from 28-day-old samples stored under dark conditions. These ages represent the oldest samples available within this study for each lighting condition, not the aging limits for each.

Unfortunately, the design of this study did not provide large enough sample sizes at each aging time for a nuanced analysis of the effects of aging. However, several general trends were apparent. For instance, a cursory analysis of fuming times indicated that, in general, the longer a print was aged prior to fuming, the longer the fuming time necessary to produce a visible print. Also, longer aging times generally yielded fewer prints that were assigned a "good" quality rating, but this decrease did not follow a smooth drop-off curve. Background polymerization results appeared to be independent of aging, because the ratings distributions followed no general trend over time, but were rather erratic.

General Treatment Option Effects

The main focus of this thesis was to assess the efficacy of the acetic acid regeneration treatment in developing children's prints when combined with cyanoacrylate fuming under conditions of high humidity. Therefore, an analysis of the quality of treated versus untreated samples was paramount.

When samples were divided into groups of 250 according to treatment option

(Table 7), a smaller proportion of treated samples were considered "good" quality prints than untreated samples. This difference was substantial enough to be considered statistically significant (whereas all differences for other rating levels were not significant). A close inspection of the samples indicated that the presence of acetic acid vapors had retarded the polymer deposition along fingerprint ridges, leaving many of the treated prints with fainter deposition than the untreated prints. Sometimes ridge detail was still clear enough and in enough abundance to warrant a "good" rating. But often a faint print was classified as "fair" quality.

Table 7: Overall Print Quality Ratings According to Treatment Option (All Samples)

		500 **Total** Samples		250 Untreated Samples		250 Treated Samples	
Overall Quality Ratings	good	199	(39.8%)	112	(44.8%)	87	(34.8%)
	fair	116	(23.2%)	51	(20.4%)	65	(26.0%)
	poor	174	(34.8%)	82	(32.8%)	92	(36.8%)
	X	11	(2.2%)	5	(2.0%)	6	(2.4%)

While surveying the reasons for individual print quality classifications, it was noted that many more treated samples than untreated samples were assigned the "fair" rating because the ridge detail was faint. In contrast, the most common reason for placing untreated samples into the "fair" category was the discontinuities found along the fingerprint ridges. It is possible to overcome the problem of faint print development by any of multiple post-fuming enhancement techniques currently available. But one cannot enhance what is not present in the first place; namely, discontinuities cannot be artificially connected to yield a smooth ridge. Therefore the application of post-fuming

enhancement techniques would very likely improve the quality ratings of treated samples more than untreated samples. Further investigation is warranted to test this hypothesis, since the investigation of post-fuming enhancement techniques fell outside the scope of this study.

When assessing the background polymerization ratings in relation to treatment option (Table 8), samples treated with acetic acid were placed into the "none" and "low" categories 89.2% of the time. Only 58.4% of those samples not exposed to acetic acid developed with similarly low levels of background polymerization. The difference between these two proportions was found to be statistically significant. Cyanoacrylate build-up on the substrate is due to polymerization initiation by the silanol groups of glass. When acetic acid was present, the "capping" of these silanol groups by the available H^+ ions led to a polymerization reduction.

Table 8: Background Polymerization Ratings According to Treatment Option (All Samples)

		500 **Total** Samples		250 Untreated Samples		250 Treated Samples	
Bkgd Polymeriz. Ratings	none	204	(40.8%)	73	(29.2%)	131	(52.4%)
	low	165	(33.0%)	73	(29.2%)	92	(36.8%)
	medium	71	(14.2%)	50	(20.0%)	21	(8.4%)
	high	60	(12.0%)	54	(21.6%)	6	(2.4%)

Detailed Treatment Option Effects

In order to gain a more detailed picture of the impact of acetic acid treatment, the groups of samples were subdivided according to additional experimental parameters.

Tables 9 and 10 on the following page display the results when all 500 samples were divided into four groups based on treatment option and print type. The differences between groups were subjected to statistical analysis (making use of the Bonferroni correction for multiple significance tests performed on the same data set, as explained in Appendix B). In terms of overall print quality (Table 9, following page), the only difference of significance was between the number of oily untreated prints and oily treated prints receiving a "good" rating.

When background polymerization was considered (Table 10, following page), both clean treated samples and oily treated samples had significantly greater numbers of prints with assigned ratings of "none" and "low" than their untreated counterparts, a difference that was more pronounced in the case of oily prints. When the comparison was made between clean treated prints and oily treated prints, the clean treated prints had a significantly lower proportion receiving a designation of "none" but a significantly higher proportion receiving a rating of "low" than the oily treated prints. These variations offset one another, for when the "none" and "low" ratings were combined, the resulting difference between clean treated and oily treated prints was not found to be significant. Though the same general trend marked the comparison of clean untreated prints with oily untreated prints, the differences were statistically insignificant.

In summary, acetic acid treatment significantly reduced the number of oily prints receiving a "good" print quality rating. In terms of background polymerization, acetic acid treatment was found to have a significant effect on limiting background build-up, particularly with oily prints.

Table 9: Overall Print Quality Ratings According to Treatment Option and Print Type (All Samples)

		500 **Total** Samples		125 Clean, Untreated Samples		125 Clean, Treated Samples		125 Oily, Untreated Samples		125 Oily, Treated Samples	
Overall Quality Ratings	good	199	(39.8%)	50	(40.0%)	45	(36.0%)	62	(49.6%)	42	(33.6%)
	fair	116	(23.2%)	26	(20.8%)	32	(25.6%)	25	(20.0%)	33	(26.4%)
	poor	174	(34.8%)	45	(36.0%)	46	(36.8%)	37	(29.6%)	46	(36.8%)
	X	11	(2.2%)	4	(3.2%)	2	(1.6%)	1	(0.8%)	4	(3.2%)

Table 10: Background Polymerization Ratings According to Treatment Option and Print Type (All Samples)

		500 **Total** Samples		125 Clean, Untreated Samples		125 Clean, Treated Samples		125 Oily, Untreated Samples		125 Oily, Treated Samples	
Bkgd Polymeriz. Ratings	none	204	(40.8%)	29	(23.2%)	48	(38.4%)	44	(35.2%)	83	(66.4%)
	low	165	(33.0%)	40	(32.0%)	60	(48.0%)	33	(26.4%)	32	(25.6%)
	medium	71	(14.2%)	28	(22.4%)	15	(12.0%)	22	(17.6%)	6	(4.8%)
	high	60	(12.0%)	28	(22.4%)	2	(1.6%)	26	(20.8%)	4	(3.2%)

The results for the grouping of the 300 samples in the restricted sample set (those prints fumed after 2 to 7 days of aging) according to treatment option and lighting condition are displayed in Tables 11 and 12 (following page). While fluorescent and simulated sunlight provided similar print quality results when treatment option was *not* taken into account (see Table 5, page 38), separating the samples by acetic acid treatment (Table 11, following page) revealed a difference between the two lighting conditions. Exposure to acetic acid halved the number of prints stored under fluorescent light that were assigned a "good" quality rating, which was determined to be a difference of significance. However, acetic acid treatment only slightly diminished the proportion of "good" prints that had been stored under the simulated sunlight, a difference that was found to be statistically insignificant. Statistical analysis of all other relevant comparisons among the six groups yielded no significance to any differences in the proportions of prints receiving various quality assessments.

In general, the use of the acetic acid treatment resulted in greater numbers of prints developing with little or no background polymerization (Table 12, following page) for all three lighting types. This was the expected result, due to the capping of the glass substrate's polymerization-initiating silanol groups by the available H^+ ions. Of note is that this difference was validated as significant by statistical analysis in the cases of the fluorescent lighting and simulated sunlight, but was not found to be significant in the case of dark storage. This situation serves to highlight the fact that the use of the Bonferroni correction, while necessary, results in the reduced likelihood that a particular perceived difference will be labeled as significant. However, it must be stressed that failure to be designated a "significant" difference does not preclude the possibility that the parameter

Table 11: Overall Print Quality Ratings According to Treatment Option and Lighting Condition (Samples Aged 2 to 7 Days)

		300 **Total** Samples		50 Dark, Untreated Samples		50 Dark, Treated Samples		50 Fluor, Untreated Samples		50 Fluor, Treated Samples		50 'Sun", Untreated Samples		50 "Sun", Treated Samples	
Overall Quality Ratings	good	113	(37.7%)	21	(42.0%)	16	(32.0%)	26	(52.0%)	12	(24.0%)	20	(40.0%)	18	(36.0%)
	fair	65	(21.7%)	8	(16.0%)	13	(26.0%)	6	(12.0%)	14	(28.0%)	11	(22.0%)	13	(26.0%)
	poor	116	(38.7%)	21	(42.0%)	19	(38.0%)	16	(32.0%)	24	(48.0%)	18	(36.0%)	18	(36.0%)
	X	6	(2.0%)	0	(0.0%)	2	(4.0%)	2	(4.0%)	0	(0.0%)	1	(2.0%)	1	(2.0%)

Table 12: Background Polymerization Ratings According to Treatment Option and Lighting Condition (Samples Aged 2 to 7 Days)

		300 **Total** Samples		50 Dark, Untreated Samples		50 Dark, Treated Samples		50 Fluor, Untreated Samples		50 Fluor, Treated Samples		50 'Sun", Untreated Samples		50 "Sun", Treated Samples	
Bkgd Polymeriz. Ratings	none	149	(49.7%)	21	(42.0%)	30	(60.0%)	17	(34.0%)	32	(64.0%)	19	(38.0%)	30	(60.0%)
	low	106	(35.3%)	21	(42.0%)	18	(36.0%)	17	(34.0%)	15	(30.0%)	16	(32.0%)	19	(38.0%)
	medium	34	(11.3%)	7	(14.0%)	2	(4.0%)	9	(18.0%)	3	(6.0%)	12	(24.0%)	1	(2.0%)
	high	11	(3.7%)	1	(2.0%)	0	(0.0%)	7	(14.0%)	0	(0.0%)	3	(6.0%)	0	(0.0%)

in question may yet have an effect on the results. In cases where the calculated z-value is just slightly less than the critical z-value, additional testing of just that parameter is warranted. (By limiting the parameters under consideration to only one, the number of significance tests drops to one test, which can be performed without consideration of the Bonferroni correction.)

Sample Pair Comparisons

Whereas the previous analyses were based on the aggregate ratings for 500 individual samples (or, when lighting conditions were being analyzed, 300 individual samples), a second type of analysis was based upon direct comparisons of the 250 available sample pairs. Depositions collected under the same conditions (either before or after hand-washing) from corresponding fingers of the left and right hands of a study participant were considered "sample pairs." Both samples in a pair were stored together under the same lighting conditions for the same length of time. The left-hand sample was then fumed without acetic acid treatment, while the right-hand sample was fumed with the acetic acid regeneration treatment. Assuming that the depositions from opposite hands were equivalent, the samples in a pair could be compared with each other to directly elucidate the effect of acetic acid treatment. In the following tables, information is presented in relation to the treated samples. That is, the term "better" indicates the treated sample had a more desirable rating than the untreated sample; the term "same" indicates that the ratings of both samples in the pairing were equal; the term "worse" indicates the treated sample had a less desirable rating than the untreated sample.

Results of the comparison of overall print quality between treated and untreated prints are presented in Table 13. The majority of all comparisons (129 out of 250, or 51.6%) demonstrated no change in the overall print quality rating due to acetic acid treatment. An improved quality rating due to acetic acid treatment was apparent in 18.8% of the comparisons (47 out of 250), while closer to one-third of the comparisons (74 out of 250, or 29.6%) depicted a deterioration in the print quality when exposed to acetic acid.

Table 13: Comparisons of the Effect of Acetic Acid Regeneration Treatment on Print Quality (All Sample Pairs)

		250 **Total** Comparisons	
Overall Print Quality	better	47	(18.8%)
	same	129	(51.6%)
	worse	74	(29.6%)

A more favorable link was found between acetic acid treatment and background polymerization levels (Table 14, following page). Of the 250 comparisons, acetic acid exposure was shown to improve the background development in half of the sample pairs. Background development was unaffected by the acetic acid treatment in an additional 40.0% of the sample pairs, leaving only 25 comparisons (10.0%) in which the acetic acid treatment led to a worse background polymerization rating.

Table 14: Comparisons of the Effect of Acetic Acid Regeneration Treatment on Background Polymerization (All Sample Pairs)

		250 **Total** Comparisons	
Bkgd Polymerization	better	125	(50.0%)
	same	100	(40.0%)
	worse	25	(10.0%)

When the comparisons were separated by print type (Table 15), acetic acid exposure was linked to an improvement in print quality in 25.6% (32 out of 125 comparisons) of the clean samples, a proportion more than twice as large as the improvement for oily samples (12.0%, or 15 out of 125 comparisons). The difference between the proportions of clean and oily samples that responded unfavorably to the acetic was not significant. While most of the comparisons, regardless of print type, reflected no change in print quality due to acetic acid treatment, the treatment was found to be more beneficial for clean samples than oily samples.

Table 15: Comparisons of the Effect of Acetic Acid Regeneration Treatment on Print Quality According to Print Type (All Sample Pairs)

		250 **Total** Comparisons		125 Clean Comparisons		125 Oily Comparisons	
Overall Print Quality	better	47	(18.8%)	32	(25.6%)	15	(12.0%)
	same	129	(51.6%)	61	(48.8%)	68	(54.4%)
	worse	74	(29.6%)	32	(25.6%)	42	(33.6%)

When background polymerization was under consideration (Table 16, following page), clean and oily prints responded similarly to acetic acid exposure, with half of the

comparisons showing an improvement in cyanoacrylate build-up (i.e. lower background polymerization level) on the glass background. Only approximately 10% of the cases for both print types showed higher background polymerization levels in the treated sample in a sample pair. Thus, acetic acid was shown to be equally effective at reducing the background polymerization of both print compositions.

Table 16: Comparisons of the Effect of Acetic Acid Regeneration Treatment on Background Polymerization According to Print Type (All Sample Pairs)

		250 **Total** Comparisons		125 Clean Comparisons		125 Oily Comparisons	
Bkgd Polymerization	better	125	(50.0%)	62	(49.6%)	63	(50.4%)
	same	100	(40.0%)	47	(37.6%)	53	(42.4%)
	worse	25	(10.0%)	16	(12.8%)	9	(7.2%)

To analyze the effect of the acetic acid treatment relative to lighting condition (Table 17, following page), the number of comparisons was restricted to 150 (representing the 150 sample pairs, or 300 total samples, that were fumed after aging times common to all three lighting options). Within this subset, maintaining the same level of print quality regardless of treatment occurred in a substantially larger percentage of sample pairs under fluorescent lighting (52.0%) and simulated sunlight (54.0%) than sample pairs kept in dark storage (28.0%). The differences among lighting options in the proportions of sample pairs yielding better print quality or worse print quality were statistically non-significant.

Table 17: Comparisons of the Effect of Acetic Acid Regeneration Treatment on Print Quality According to Lighting Condition (Sample Pairs Aged 2 to 7 Days)

		150 **Total** Comparisons		50 Dark Comparisons		50 Fluor. Comparisons		50 "Sunlight" Comparisons	
Overall Print Quality	better	30	(20.0%)	13	(26.0%)	6	(12.0%)	11	(22.0%)
	same	67	(44.7%)	14	(28.0%)	26	(52.0%)	27	(54.0%)
	worse	53	(35.3%)	23	(46.0%)	18	(36.0%)	12	(24.0%)

In terms of background polymerization (Table 18), similar responses were found across all three lighting conditions, with any differences among lighting options being ruled statistically insignificant. Thus, acetic acid treatment is effective in relation to background polymerization ratings regardless of lighting conditions.

Table 18: Comparisons of the Effect of Acetic Acid Regeneration Treatment on Print Quality and Background Polymerization According to Lighting Condition

		150 **Total** Comparisons		50 Dark Comparisons		50 Fluor. Comparisons		50 "Sunlight" Comparisons	
Bkgd Polymerization	better	63	(42.0%)	20	(40.0%)	24	(48.0%)	19	(38.0%)
	same	69	(46.0%)	22	(44.0%)	21	(42.0%)	26	(52.0%)
	worse	18	(12.0%)	8	(16.0%)	5	(10.0%)	5	(10.0%)

Chapter 4

CONCLUSION

The results of a study of the efficacy of acetic acid as a regeneration agent for children's prints, when coupled with cyanoacrylate fuming at high humidity, have been presented. A regeneration treatment protocol was modified and optimized into a one-step fuming process utilizing a 2:1 w/w cyanoacrylate ester: acetic acid mixture. The process was applied to 500 individual samples from 25 pre-pubescent children after given periods of storage in one of three lighting conditions: dark storage, fluorescent lighting, and simulated sunlight. After development, each print was classified by background polymerization and overall print quality.

In direct comparisons of treated and untreated samples, the acetic acid treatment was found to substantially improve the background polymerization of a sample to low or unnoticeable levels. Exactly 50.0% of the samples receiving the acetic acid treatment were classified with lower background polymerization than their untreated counterparts; only 10.0% of treated samples were classified with higher background polymerization. The two print types were affected similarly by the treatment. Likewise, the three lighting conditions responded similarly to acetic acid exposure. However, moving away from direct comparisons of sample pairs and shifting focus to totals of each of the four background levels, there were some significant differences. Substantially more oily prints developed with "none" or "low" background ratings than clean prints. Treatment

was linked with a larger increase in the number of prints given the "none" or "low" ratings from those stored in fluorescent and simulated sunlight than those stored in the dark.

Background polymerization can interfere with and even obscure ridge details, so it plays a role in print quality (a more important consideration for print examiners than background cyanoacrylate build-up). However, a reduction of background polymerization is not always synonymous with an improvement in overall print quality. Additionally, prints with elevated levels of background build-up can still be considered prints of good quality if the background is not localized to print furrows, or if the ridge development is well-defined to compensate for any background interference.

Based on direct comparisons of sample pairs, 18.8% of the treated samples had improved quality ratings over the untreated sample in the pair. An additional 51.6% of the samples had quality ratings that remained unchanged by exposure to acetic acid, leaving a sizeable 29.6% of the cases with worse quality ratings after treatment. The treatment was significantly more effective at improving quality in clean samples than in oily samples. When lighting option was analyzed, significantly more samples under fluorescent light and simulated sunlight maintained the same quality rating than samples stored in the dark. Analyzing the data in terms of the totals of each of the four specific quality levels, oily prints and prints subjected to fluorescent lighting were found to have significantly higher quality ratings without the acetic acid treatment, but the remaining print type and lighting conditions were not significantly affected by the treatment.

The results of this study are promising. With refinement, and in combination with post-fuming enhancement techniques, the acetic acid technique may be capable of

producing consistent improvement in the quality of samples fumed at high humidity.

APPENDICES

APPENDIX A

Participant Information & Sample Set Storage and Fuming Plans

Table 19: Gender and Age of Each Participant

PARTICIPANT NUMBER	GENDER	AGE
1	F	5
2	F	5
3	F	5
4	M	5
5	F	4
6	M	5
7	F	5
8	M	5
9	M	4
10	M	5
11	M	5
12	F	5
13	F	4
14	M	5
15	M	5
16	F	4
17	F	4
18	F	3
19	F	3
20	M	3
21	F	4
22	F	2
23	F	3
24	M	3
25	F	3

Table 20: Storage Plan for 500 Samples from 25 Child Participants

Sample Set #	Lighting	Aging Duration	CLEAN ("After hand-washing")					OILY ("Before hand-washing")				
			a, f	b, g	c, h	d, i	e, j	a, f	b, g	c, h	d, i	e, j
1	None	None	Ch. #1	Ch. #5	Ch. #18	Ch. #4	Ch. #6	Ch. #2	Ch. #13	Ch. #19	Ch. #8	Ch. #20
8	Dark	2 days	Ch. #3	Ch. #16	Ch. #22	Ch. #10	Ch. #11	Ch. #7	Ch. #21	Ch. #23	Ch. #14	Ch. #24
11	Dark	3 days	Ch. #7	Ch. #21	Ch. #23	Ch. #14	Ch. #24	Ch. #12	Ch. #17	Ch. #25	Ch. #15	Ch. #9
14	Dark	4 days	Ch. #17	Ch. #25	Ch. #15	Ch. #9	Ch. #12	Ch. #5	Ch. #18	Ch. #4	Ch. #6	Ch. #1
17	Dark	5 days	Ch. #18	Ch. #4	Ch. #6	Ch. #1	Ch. #5	Ch. #19	Ch. #8	Ch. #20	Ch. #2	Ch. #13
20	Dark	7 days	Ch. #19	Ch. #8	Ch. #20	Ch. #2	Ch. #13	Ch. #22	Ch. #10	Ch. #11	Ch. #3	Ch. #16
23	Dark	14 days	Ch. #10	Ch. #11	Ch. #3	Ch. #16	Ch. #22	Ch. #14	Ch. #24	Ch. #7	Ch. #21	Ch. #23
24	Dark	21 days	Ch. #14	Ch. #24	Ch. #7	Ch. #21	Ch. #23	Ch. #15	Ch. #9	Ch. #12	Ch. #17	Ch. #25
25	Dark	28 days	Ch. #9	Ch. #12	Ch. #17	Ch. #25	Ch. #15	Ch. #6	Ch. #1	Ch. #5	Ch. #18	Ch. #4
2	Fluor.	1.5 hrs	Ch. #12	Ch. #17	Ch. #25	Ch. #15	Ch. #9	Ch. #1	Ch. #5	Ch. #18	Ch. #4	Ch. #6
4	Fluor.	3 hrs	Ch. #5	Ch. #18	Ch. #4	Ch. #6	Ch. #1	Ch. #13	Ch. #19	Ch. #8	Ch. #20	Ch. #2
6	Fluor.	18 hrs	Ch. #13	Ch. #19	Ch. #8	Ch. #20	Ch. #2	Ch. #16	Ch. #22	Ch. #10	Ch. #11	Ch. #3
9	Fluor.	2 days	Ch. #22	Ch. #10	Ch. #11	Ch. #3	Ch. #16	Ch. #23	Ch. #14	Ch. #24	Ch. #7	Ch. #21
12	Fluor.	3 days	Ch. #23	Ch. #14	Ch. #24	Ch. #7	Ch. #21	Ch. #25	Ch. #15	Ch. #9	Ch. #12	Ch. #17
15	Fluor.	4 days	Ch. #15	Ch. #9	Ch. #12	Ch. #17	Ch. #25	Ch. #4	Ch. #6	Ch. #1	Ch. #5	Ch. #18
18	Fluor.	5 days	Ch. #6	Ch. #1	Ch. #5	Ch. #18	Ch. #4	Ch. #20	Ch. #2	Ch. #13	Ch. #19	Ch. #8
21	Fluor.	7 days	Ch. #20	Ch. #2	Ch. #13	Ch. #19	Ch. #8	Ch. #11	Ch. #3	Ch. #16	Ch. #22	Ch. #10
3	"Sun"	1.5 hrs	Ch. #2	Ch. #13	Ch. #19	Ch. #8	Ch. #20	Ch. #3	Ch. #16	Ch. #22	Ch. #10	Ch. #11
5	"Sun"	3 hrs	Ch. #16	Ch. #22	Ch. #10	Ch. #11	Ch. #3	Ch. #21	Ch. #23	Ch. #14	Ch. #24	Ch. #7
7	"Sun"	18 hrs	Ch. #21	Ch. #23	Ch. #14	Ch. #24	Ch. #7	Ch. #17	Ch. #25	Ch. #15	Ch. #9	Ch. #12
10	"Sun"	2 days	Ch. #25	Ch. #15	Ch. #9	Ch. #12	Ch. #17	Ch. #18	Ch. #4	Ch. #6	Ch. #1	Ch. #5
13	"Sun"	3 days	Ch. #4	Ch. #6	Ch. #1	Ch. #5	Ch. #18	Ch. #8	Ch. #20	Ch. #2	Ch. #13	Ch. #19
16	"Sun"	4 days	Ch. #8	Ch. #20	Ch. #2	Ch. #13	Ch. #19	Ch. #10	Ch. #11	Ch. #3	Ch. #16	Ch. #22
19	"Sun"	5 days	Ch. #11	Ch. #3	Ch. #16	Ch. #22	Ch. #10	Ch. #24	Ch. #7	Ch. #21	Ch. #23	Ch. #14
22	"Sun"	7 days	Ch. #24	Ch. #7	Ch. #21	Ch. #23	Ch. #14	Ch. #9	Ch. #12	Ch. #17	Ch. #25	Ch. #15

"Ch." = child; "a" through "e" represent the thumb through little finger of the left hand, "f" through "j" represent same on right hand

Table 21: Storage and Fuming Conditions for Each Sample Set

Sample Set #	Storage Conditions		Fuming Conditions					
	Lighting	Aging Duration	Voltage (V) Provided to Humidifier	Humidifier Setting	Airflow Rate (L/min)	Hotplate Model	Hotplate Position	Hotplate Surface Temp (°C)
1	None	None	85	2	10	Corning	under	150
2	Fluor.	1.5 hrs	70	2	10	Corning	under	150
3	"Sun"	1.5 hrs	70	2	10	Corning	under	150
4	Fluor.	3 hrs	70	2	10	Corning	under	150
5	"Sun"	3 hrs	70	2	10	Corning	under	150
6	Fluor.	18 hrs	70	2	10	Corning	under	150
7	"Sun"	18 hrs	70	2	10	Corning	under	150
8	Dark	2 days	75	2	10	Cole-Pal.	level	150
9	Fluor.	2 days	75	2	10	Cole-Pal.	level	150
10	"Sun"	2 days	75	2	10	Cole-Pal.	level	150
11	Dark	3 days	75	2	10	Cole-Pal.	level	150
12	Fluor.	3 days	75	2	10	Cole-Pal.	level	150
13	"Sun"	3 days	75	2	10	Cole-Pal.	level	150
14	Dark	4 days	75	2	10	Cole-Pal.	level	150
15	Fluor.	4 days	75	2	10	Cole-Pal.	level	150
16	"Sun"	4 days	75	2	10	Cole-Pal.	level	150
17	Dark	5 days	75	2	10	Cole-Pal.	level	150
18	Fluor.	5 days	75	2	10	Cole-Pal.	level	150
19	"Sun"	5 days	75	2	10	Cole-Pal.	level	150
20	Dark	7 days	75	2	10	Cole-Pal.	level	150
21	Fluor.	7 days	75	2	10	Cole-Pal.	level	150
22	"Sun"	7 days	75	2	10	Cole-Pal.	level	150
23	Dark	14 days	75	2	10	Cole-Pal.	level	150
24	Dark	21 days	75	2	10	Cole-Pal.	level	150
25	Dark	28 days	75	2	10	Cole-Pal.	level	150

where "under" means the hotplate was positioned underneath the fuming chamber's metal platform, and "level" means the hotplate was raised so it was level with the bottom of the fuming chamber

APPENDIX B

Statistical Analysis

To determine if the differences in ratings between two categories of prints (for example, clean prints versus oily prints) were of relevance, the test of differences between proportions was performed for each rating level. For each test, the null hypothesis, that the two proportions under consideration are equal, is written H_0: $p_1 = p_2$. The alternate hypothesis, that the two proportions are not equal, is written H_1: $p_1 \neq p_2$. The computations involved are:

$$p = \frac{p_1 + p_2}{2}$$

$$s_{p_1 - p_2} = \sqrt{\frac{2p(1-p)}{n}}$$

$$z_{calc} = \frac{p_1 - p_2}{s_{p_1 - p_2}}$$

where n is the sample size (or total number of prints) in a given category, p_1 is the proportion of n with the given rating level in the first category, p_2 is the proportion of n with the given rating level in the second category, and $s_{p_1 - p_2}$ is the estimated standard error of the difference between proportions. Slightly more complicated equations would have been necessary if the two categories under comparison contained different sample sizes (n_1 and n_2). No such incident occurred in the analysis of the data used in this study.

Once z_{CALC} is determined, it is compared with the appropriate critical value, z_{CRIT}, from the z-table. If z_{CALC} is less than z_{CRIT}, the null hypothesis is accepted and no statistical significance is found. If z_{CALC} is less than z_{CRIT}, the null hypothesis is rejected and the difference between the two proportions is said to be statistically significant. In the analyses presented in this appendix:

$\alpha = 0.05$ (a confidence interval of 95%)

$$z_{CRIT,\,0.05} = 1.96$$

However, if multiple statistical tests are performed on a data set, the Bonferroni correction must be used. According to this correction, multiple tests increase the likelihood beyond 5% that a chance occurrence will be incorrectly interpreted as a significant correlation. To reset the 5% limit, α for each test must be adjusted downward. The new value, α_B, is related to the number of significance tests, k, as follows:

$$\alpha_B = \alpha/k = 0.05/k$$

In the tables presented in this appendix, statistical analysis is summarized for the data presented in Table 3 through Table 12 and Table 15 through Table 18 in the main text of this thesis. Below each table, the values for n, k, and α_B are presented.

Table 22: Statistical Analysis of Table 3 (Overall Print Quality Ratings According to Print Type - All Samples)

		Rating Level	p_1	p_2	p	s_{p1-p2}	z_{CALC}	$z_{CRIT,0.05}$	difference significant?
p_1 = Clean Samples	p_2 = Oily Samples	good	0.380	0.416	0.398	0.044	0.822	1.96	no
		fair	0.232	0.232	0.232	0.038	0.000	1.96	no
		poor	0.364	0.332	0.348	0.043	0.751	1.96	no
		X	0.024	0.020	0.022	0.013	0.305	1.96	no
		(good + fair)	0.612	0.648	0.630	0.043	0.834	1.96	no
		(poor + X)	0.388	0.352	0.370	0.043	0.834	1.96	no

n = 500
k = 1
$\alpha_B = \alpha/k = 0.05/1 = 0.05$

Table 23: Statistical Analysis of Table 4 (Background Polymerization Ratings According to Print Type - All Samples)

		Rating Level	p_1	p_2	p	s_{p1-p2}	z_{CALC}	$z_{CRIT,0.05}$	difference significant?
p_1 = Clean Samples	p_2 = Oily Samples	none	0.308	0.508	0.408	0.044	4.550	1.96	yes
		low	0.400	0.260	0.330	0.042	3.329	1.96	yes
		medium	0.172	0.112	0.142	0.031	1.922	1.96	no
		high	0.120	0.120	0.120	0.029	0.000	1.96	no
		(none + low)	0.708	0.768	0.738	0.039	1.526	1.96	no
		(med. + high)	0.292	0.232	0.262	0.039	1.526	1.96	no

n = 500
k = 1
$\alpha_B = \alpha/k = 0.05/1 = 0.05$

Table 24: Statistical Analysis of Table 5 (Overall Print Quality Ratings According to Lighting Conditions - Samples Aged 2 to 7 Days)

		Rating Level	p_1	p_2	p	s_{p1-p2}	z_{CALC}	$z_{CRIT,0.017}$	difference significant?
p_1 = Dark Samples	p_2 = Fluor. Samples	good	0.370	0.380	0.375	0.068	0.146	2.39	no
		fair	0.210	0.200	0.205	0.057	0.175	2.39	no
		poor	0.400	0.400	0.400	0.069	0.000	2.39	no
		X	0.020	0.020	0.020	0.020	0.000	2.39	no
		(good + fair)	0.580	0.580	0.580	0.070	0.000	2.39	no
		(poor + X)	0.420	0.420	0.420	0.070	0.000	2.39	no
p_1 = Dark Samples	p_2 = "Sun" Samples	good	0.370	0.380	0.375	0.068	0.146	2.39	no
		fair	0.210	0.240	0.225	0.059	0.508	2.39	no
		poor	0.400	0.360	0.380	0.069	0.583	2.39	no
		X	0.020	0.020	0.020	0.020	0.000	2.39	no
		(good + fair)	0.580	0.620	0.600	0.069	0.577	2.39	no
		(poor + X)	0.420	0.380	0.400	0.069	0.577	2.39	no
p_1 = Fluor. Samples	p_2 = "Sun" Samples	good	0.380	0.380	0.380	0.069	0.000	2.39	no
		fair	0.200	0.240	0.220	0.059	0.683	2.39	no
		poor	0.400	0.360	0.380	0.069	0.583	2.39	no
		X	0.020	0.020	0.020	0.020	0.000	2.39	no
		(good + fair)	0.580	0.620	0.600	0.069	0.577	2.39	no
		(poor + X)	0.420	0.380	0.400	0.069	0.577	2.39	no

n = 300
k = 3
$\alpha_B = \alpha/k = 0.05/3 = 0.017$

Table 25: Statistical Analysis of Table 6 (Background Polymerization Ratings According to Lighting Conditions - Samples Aged 2 to 7 Days)

		Rating Level	p_1	p_2	p	s_{p1-p2}	z_{CALC}	$z_{CRIT,0.017}$	difference significant?
p_1 = Dark Samples	p_2 = Fluor. Samples	none	0.510	0.490	0.500	0.071	0.283	2.39	no
		low	0.390	0.320	0.355	0.068	1.034	2.39	no
		medium	0.090	0.120	0.105	0.043	0.692	2.39	no
		high	0.010	0.070	0.040	0.028	2.165	2.39	no
		(none + low)	0.900	0.810	0.855	0.050	1.807	2.39	no
		(med. + high)	0.100	0.190	0.145	0.050	1.807	2.39	no
p_1 = Dark Samples	p_2 = "Sun" Samples	none	0.510	0.490	0.500	0.071	0.283	2.39	no
		low	0.390	0.350	0.370	0.068	0.586	2.39	no
		medium	0.090	0.130	0.110	0.044	0.904	2.39	no
		high	0.010	0.030	0.020	0.020	1.010	2.39	no
		(none + low)	0.900	0.840	0.870	0.048	1.262	2.39	no
		(med. + high)	0.100	0.160	0.130	0.048	1.262	2.39	no
p_1 = Fluor. Samples	p_2 = "Sun" Samples	none	0.490	0.490	0.490	0.071	0.000	2.39	no
		low	0.320	0.350	0.335	0.067	0.449	2.39	no
		medium	0.120	0.130	0.125	0.047	0.214	2.39	no
		high	0.070	0.030	0.050	0.031	1.298	2.39	no
		(none + low)	0.810	0.840	0.825	0.054	0.558	2.39	no
		(med. + high)	0.190	0.160	0.175	0.054	0.558	2.39	no

n = 300

k = 3

$\alpha_B = \alpha/k = 0.05/3 = 0.017$

Table 26: Statistical Analysis of Table 7 (Overall Print Quality Ratings According to Treatment Option - All Samples)

		Rating Level	p_1	p_2	p	s_{p1-p2}	z_{CALC}	$z_{CRIT,0.05}$	difference significant?
p_1 = Untreated Samples	p_2 = Treated Samples	good	0.448	0.348	0.398	0.044	2.284	1.96	yes
		fair	0.204	0.260	0.232	0.038	1.483	1.96	no
		poor	0.328	0.368	0.348	0.043	0.939	1.96	no
		X	0.020	0.024	0.022	0.013	0.305	1.96	no
		(good + fair)	0.652	0.608	0.630	0.043	1.019	1.96	no
		(poor + X)	0.348	0.392	0.370	0.043	1.019	1.96	no

n = 500
k = 1
$\alpha_B = \alpha/k = 0.05/1 = 0.05$

Table 27: Statistical Analysis of Table 8 (Background Polymerization Ratings According to Treatment Option - All Samples)

		Rating Level	p_1	p_2	p	s_{p1-p2}	z_{CALC}	$z_{CRIT,0.05}$	difference significant?
p_1 = Untreated Samples	p_2 = Treated Samples	none	0.292	0.524	0.408	0.044	5.278	1.96	yes
		low	0.292	0.368	0.330	0.042	1.807	1.96	no
		medium	0.200	0.084	0.142	0.031	3.716	1.96	yes
		high	0.216	0.024	0.120	0.029	6.606	1.96	yes
		(none + low)	0.584	0.892	0.738	0.039	7.831	1.96	yes
		(med. + high)	0.416	0.108	0.262	0.039	7.831	1.96	yes

n = 500
k = 1
$\alpha_B = \alpha/k = 0.05/1 = 0.05$

Table 28: Statistical Analysis of Table 9 (Overall Print Quality Ratings According to Treatment Option and Print Type - All Samples)

		Rating Level	p_1	p_2	p	s_{p1-p2}	z_{CALC}	$z_{CRIT,0.0125}$	difference significant?
p_1 = Untreated, Clean Samples	p_2 = Treated, Clean Samples	good	0.400	0.360	0.380	0.061	0.651	2.5	no
		fair	0.208	0.256	0.232	0.053	0.899	2.5	no
		poor	0.360	0.368	0.364	0.061	0.131	2.5	no
		X	0.032	0.016	0.024	0.019	0.826	2.5	no
		(good + fair)	0.608	0.616	0.612	0.062	0.130	2.5	no
		(poor + X)	0.392	0.384	0.388	0.062	0.130	2.5	no
p_1 = Untreated, Oily Samples	p_2 = Treated, Oily Samples	good	0.496	0.336	0.416	0.062	2.566	2.5	yes
		fair	0.200	0.264	0.232	0.053	1.199	2.5	no
		poor	0.296	0.368	0.332	0.060	1.209	2.5	no
		X	0.008	0.032	0.020	0.018	1.355	2.5	no
		(good + fair)	0.696	0.600	0.648	0.060	1.589	2.5	no
		(poor + X)	0.304	0.400	0.352	0.060	1.589	2.5	no
p_1 = Untreated, Clean Samples	p_2 = Untreated, Oily Samples	good	0.400	0.496	0.448	0.063	1.526	2.5	no
		fair	0.208	0.200	0.204	0.051	0.157	2.5	no
		poor	0.360	0.296	0.328	0.059	1.078	2.5	no
		X	0.032	0.008	0.020	0.018	1.355	2.5	no
		(good + fair)	0.608	0.696	0.652	0.060	1.461	2.5	no
		(poor + X)	0.392	0.304	0.348	0.060	1.461	2.5	no
p_1 = Treated, Clean Samples	p_2 = Treated, Oily Samples	good	0.360	0.336	0.348	0.060	0.398	2.5	no
		fair	0.256	0.264	0.260	0.055	0.144	2.5	no
		poor	0.368	0.368	0.368	0.061	0.000	2.5	no
		X	0.016	0.032	0.024	0.019	0.826	2.5	no
		(good + fair)	0.616	0.600	0.608	0.062	0.259	2.5	no
		(poor + X)	0.384	0.400	0.392	0.062	0.259	2.5	no

Comparisons not of interest: p_1 = Untreated, Clean samples; p_2 = Treated, Oily samples
p_1 = Treated, Clean samples; p_2 = Untreated, Oily samples

$n = 500$
$k = 4$
$\alpha_B = \alpha/k = 0.05/4 = 0.0125$

Table 29: Statistical Analysis of Table 10 (Background Polymerization Ratings According to Treatment Option and Print Type - All Samples)

		Rating Level	p_1	p_2	p	s_{p1-p2}	z_{CALC}	$z_{CRIT,0.0125}$	difference significant?
p_1 = Untreated, Clean Samples	p_2 = Treated, Clean Samples	none	0.232	0.384	0.308	0.058	2.603	2.5	yes
		low	0.320	0.480	0.400	0.062	2.582	2.5	yes
		medium	0.224	0.120	0.172	0.048	2.179	2.5	no
		high	0.224	0.016	0.120	0.041	5.060	2.5	yes
		(none + low)	0.552	0.864	0.708	0.058	5.425	2.5	yes
		(med. + high)	0.448	0.136	0.292	0.058	5.425	2.5	yes
p_1 = Untreated, Oily Samples	p_2 = Treated, Oily Samples	none	0.352	0.664	0.508	0.063	4.934	2.5	yes
		low	0.264	0.256	0.260	0.055	0.144	2.5	no
		medium	0.176	0.048	0.112	0.040	3.209	2.5	yes
		high	0.208	0.032	0.120	0.041	4.282	2.5	yes
		(none + low)	0.616	0.920	0.768	0.053	5.694	2.5	yes
		(med. + high)	0.384	0.080	0.232	0.053	5.694	2.5	yes
p_1 = Untreated, Clean Samples	p_2 = Untreated, Oily Samples	none	0.232	0.352	0.292	0.058	2.086	2.5	no
		low	0.320	0.264	0.292	0.058	0.974	2.5	no
		medium	0.224	0.176	0.200	0.051	0.949	2.5	no
		high	0.224	0.208	0.216	0.052	0.307	2.5	no
		(none + low)	0.552	0.616	0.584	0.062	1.027	2.5	no
		(med. + high)	0.448	0.384	0.416	0.062	1.027	2.5	no
p_1 = Treated, Clean Samples	p_2 = Treated, Oily Samples	none	0.384	0.664	0.524	0.063	4.432	2.5	yes
		low	0.480	0.256	0.368	0.061	3.672	2.5	yes
		medium	0.120	0.048	0.084	0.035	2.052	2.5	no
		high	0.016	0.032	0.024	0.019	0.826	2.5	no
		(none + low)	0.864	0.920	0.892	0.039	1.426	2.5	no
		(med. + high)	0.136	0.080	0.108	0.039	1.426	2.5	no

Comparisons not of interest: p_1 = Untreated, Clean samples; p_2 = Treated, Oily samples
p_1 = Treated, Clean samples; p_2 = Untreated, Oily samples

$n = 500$
$k = 4$
$\alpha_B = \alpha/k = 0.05/4 = 0.0125$

Table 30: Statistical Analysis of Table 11 (Overall Print Quality Ratings According to Treatment Option and Lighting Condition - Samples Aged 2 to 7 Days)

		Rating Level	p_1	p_2	p	$s_{p1\text{-}p2}$	z_{CALC}	$z_{CRIT,0.0056}$	difference significant?
p_1 = Untreated, Dark Samples	p_2 = Treated, Dark Samples	good	0.420	0.320	0.370	0.097	1.036	2.77	no
		fair	0.160	0.260	0.210	0.081	1.228	2.77	no
		poor	0.420	0.380	0.400	0.098	0.408	2.77	no
		X	0.000	0.040	0.020	0.028	1.429	2.77	no
		(good + fair)	0.580	0.580	0.580	0.099	0.000	2.77	no
		(poor + X)	0.420	0.420	0.420	0.099	0.000	2.77	no
p_1 = Untreated, Fluor. Samples	p_2 = Treated, Fluor. Samples	good	0.520	0.240	0.380	0.097	2.884	2.77	yes
		fair	0.120	0.280	0.200	0.080	2.000	2.77	no
		poor	0.320	0.480	0.400	0.098	1.633	2.77	no
		X	0.040	0.000	0.020	0.028	1.429	2.77	no
		(good + fair)	0.640	0.520	0.580	0.099	1.216	2.77	no
		(poor + X)	0.360	0.480	0.420	0.099	1.216	2.77	no
p_1 = Untreated, "Sun" Samples	p_2 = Treated, "Sun" Samples	good	0.400	0.360	0.380	0.097	0.412	2.77	no
		fair	0.220	0.260	0.240	0.085	0.468	2.77	no
		poor	0.360	0.360	0.360	0.096	0.000	2.77	no
		X	0.020	0.020	0.020	0.028	0.000	2.77	no
		(good + fair)	0.620	0.620	0.620	0.097	0.000	2.77	no
		(poor + X)	0.380	0.380	0.380	0.097	0.000	2.77	no
p_1 = Untreated, Dark Samples	p_2 = Untreated, Fluor. Samples	good	0.420	0.520	0.470	0.100	1.002	2.77	no
		fair	0.160	0.120	0.140	0.069	0.576	2.77	no
		poor	0.420	0.320	0.370	0.097	1.036	2.77	no
		X	0.000	0.040	0.020	0.028	1.429	2.77	no
		(good + fair)	0.580	0.640	0.610	0.098	0.615	2.77	no
		(poor + X)	0.420	0.360	0.390	0.098	0.615	2.77	no
p_1 = Untreated, Dark Samples	p_2 = Untreated, "Sun" Samples	good	0.420	0.400	0.410	0.098	0.203	2.77	no
		fair	0.160	0.220	0.190	0.078	0.765	2.77	no
		poor	0.420	0.360	0.390	0.098	0.615	2.77	no
		X	0.000	0.020	0.010	0.020	1.005	2.77	no
		(good + fair)	0.580	0.620	0.600	0.098	0.408	2.77	no
		(poor + X)	0.420	0.380	0.400	0.098	0.408	2.77	no
p_1 = Untreated, Fluor. Samples	p_2 = Untreated, "Sun" Samples	good	0.520	0.400	0.460	0.100	1.204	2.77	no
		fair	0.120	0.220	0.170	0.075	1.331	2.77	no
		poor	0.320	0.360	0.340	0.095	0.422	2.77	no
		X	0.040	0.020	0.030	0.034	0.586	2.77	no
		(good + fair)	0.640	0.620	0.630	0.097	0.207	2.77	no
		(poor + X)	0.360	0.380	0.370	0.097	0.207	2.77	no

Table 30 (con'd)

		Rating Level	p_1	p_2	p	s_{p1-p2}	z_{CALC}	$z_{CRIT,0.0056}$	difference significant?
p_1 = Treated, Dark Samples	p_2 = Treated, Fluor. Samples	good	0.320	0.240	0.280	0.090	0.891	2.77	no
		fair	0.260	0.280	0.270	0.089	0.225	2.77	no
		poor	0.380	0.480	0.430	0.099	1.010	2.77	no
		X	0.040	0.000	0.020	0.028	1.429	2.77	no
		(good + fair)	0.580	0.520	0.550	0.099	0.603	2.77	no
		(poor + X)	0.420	0.480	0.450	0.099	0.603	2.77	no
p_1 = Treated, Dark Samples	p_2 = Treated, "Sun" Samples	good	0.320	0.360	0.340	0.095	0.422	2.77	no
		fair	0.260	0.260	0.260	0.088	0.000	2.77	no
		poor	0.380	0.360	0.370	0.097	0.207	2.77	no
		X	0.040	0.020	0.030	0.034	0.586	2.77	no
		(good + fair)	0.580	0.620	0.600	0.098	0.408	2.77	no
		(poor + X)	0.420	0.380	0.400	0.098	0.408	2.77	no
p_1 = Treated, Fluor. Samples	p_2 = Treated, "Sun" Samples	good	0.240	0.360	0.300	0.092	1.309	2.77	no
		fair	0.280	0.260	0.270	0.089	0.225	2.77	no
		poor	0.480	0.360	0.420	0.099	1.216	2.77	no
		X	0.000	0.020	0.010	0.020	1.005	2.77	no
		(good + fair)	0.520	0.620	0.570	0.099	1.010	2.77	no
		(poor + X)	0.480	0.380	0.430	0.099	1.010	2.77	no

Comparisons not of interest: p_1 = Untreated, Dark samples; p_2 = Treated, Fluor. samples
p_1 = Untreated, Dark samples; p_2 = Treated, "Sun" samples
p_1 = Treated, Dark samples; p_2 = Untreated, Fluor. samples
p_1 = Treated, Dark samples; p_2 = Untreated, "Sun" samples
p_1 = Untreated, Fluor samples; p_2 = Treated, "Sun" samples
p_1 = Treated, Fluor samples; p_2 = Untreated, "Sun" samples

$n = 300$
$k = 9$
$\alpha_B = \alpha/k = 0.05/9 = 0.0056$

Table 31: Statistical Analysis of Table 12 (Background Polymerization Ratings According to Treatment Option and Lighting Condition - Samples Aged 2 to 7 Days)

		Rating Level	p_1	p_2	p	s_{p1-p2}	z_{CALC}	$z_{CRIT,0.0056}$	difference significant?
p_1 = Untreated, Dark Samples	p_2 = Treated, Dark Samples	none	0.420	0.600	0.510	0.100	1.800	2.77	no
		low	0.420	0.360	0.390	0.098	0.615	2.77	no
		medium	0.140	0.040	0.090	0.057	1.747	2.77	no
		high	0.020	0.000	0.010	0.020	1.005	2.77	no
		(none + low)	0.840	0.960	0.900	0.060	2.000	2.77	no
		(med. + high)	0.160	0.040	0.100	0.060	2.000	2.77	no
p_1 = Untreated, Fluor. Samples	p_2 = Treated, Fluor. Samples	none	0.340	0.640	0.490	0.100	3.001	2.77	yes
		low	0.340	0.300	0.320	0.093	0.429	2.77	no
		medium	0.180	0.060	0.120	0.065	1.846	2.77	no
		high	0.140	0.000	0.070	0.051	2.744	2.77	no
		(none + low)	0.680	0.940	0.810	0.078	3.314	2.77	yes
		(med. + high)	0.320	0.060	0.190	0.078	3.314	2.77	yes
p_1 = Untreated, "Sun" Samples	p_2 = Treated, "Sun" Samples	none	0.380	0.600	0.490	0.100	2.200	2.77	no
		low	0.320	0.380	0.350	0.095	0.629	2.77	no
		medium	0.240	0.020	0.130	0.067	3.271	2.77	yes
		high	0.060	0.000	0.030	0.034	1.759	2.77	no
		(none + low)	0.700	0.980	0.840	0.073	3.819	2.77	yes
		(med. + high)	0.300	0.020	0.160	0.073	3.819	2.77	yes
p_1 = Untreated, Dark Samples	p_2 = Untreated, Fluor. Samples	none	0.420	0.340	0.380	0.097	0.824	2.77	no
		low	0.420	0.340	0.380	0.097	0.824	2.77	no
		medium	0.140	0.180	0.160	0.073	0.546	2.77	no
		high	0.020	0.140	0.080	0.054	2.212	2.77	no
		(none + low)	0.840	0.680	0.760	0.085	1.873	2.77	no
		(med. + high)	0.160	0.320	0.240	0.085	1.873	2.77	no
p_1 = Untreated, Dark Samples	p_2 = Untreated, "Sun" Samples	none	0.420	0.380	0.400	0.098	0.408	2.77	no
		low	0.420	0.320	0.370	0.097	1.036	2.77	no
		medium	0.140	0.240	0.190	0.078	1.275	2.77	no
		high	0.020	0.060	0.040	0.039	1.021	2.77	no
		(none + low)	0.840	0.700	0.770	0.084	1.663	2.77	no
		(med. + high)	0.160	0.300	0.230	0.084	1.663	2.77	no
p_1 = Untreated, Fluor. Samples	p_2 = Untreated, "Sun" Samples	none	0.340	0.380	0.360	0.096	0.417	2.77	no
		low	0.340	0.320	0.330	0.094	0.213	2.77	no
		medium	0.180	0.240	0.210	0.081	0.737	2.77	no
		high	0.140	0.060	0.100	0.060	1.333	2.77	no
		(none + low)	0.680	0.700	0.690	0.092	0.216	2.77	no
		(med. + high)	0.320	0.300	0.310	0.092	0.216	2.77	no

Table 31 (con'd)

		Rating Level	p_1	p_2	p	s_{p1-p2}	z_{CALC}	$z_{CRIT,0.0056}$	difference significant?
p_1 = Treated, Dark Samples	p_2 = Treated, Fluor. Samples	none	0.600	0.640	0.620	0.097	0.412	2.77	no
		low	0.360	0.300	0.330	0.094	0.638	2.77	no
		medium	0.040	0.060	0.050	0.044	0.459	2.77	no
		high	0.000	0.000	0.000	0.000	-	2.77	no
		(none + low)	0.960	0.940	0.950	0.044	0.459	2.77	no
		(med. + high)	0.040	0.060	0.050	0.044	0.459	2.77	no
p_1 = Treated, Dark Samples	p_2 = Treated, "Sun" Samples	none	0.600	0.600	0.600	0.098	0.000	2.77	no
		low	0.360	0.380	0.370	0.097	0.207	2.77	no
		medium	0.040	0.020	0.030	0.034	0.586	2.77	no
		high	0.000	0.000	0.000	0.000	-	2.77	no
		(none + low)	0.960	0.980	0.970	0.034	0.586	2.77	no
		(med. + high)	0.040	0.020	0.030	0.034	0.586	2.77	no
p_1 = Treated, Fluor. Samples	p_2 = Treated, "Sun" Samples	none	0.640	0.600	0.620	0.097	0.412	2.77	no
		low	0.300	0.380	0.340	0.095	0.844	2.77	no
		medium	0.060	0.020	0.040	0.039	1.021	2.77	no
		high	0.000	0.000	0.000	0.000	-	2.77	no
		(none + low)	0.940	0.980	0.960	0.039	1.021	2.77	no
		(med. + high)	0.060	0.020	0.040	0.039	1.021	2.77	no

Comparisons not of interest: p_1 = Untreated, Dark samples; p_2 = Treated, Fluor. samples
p_1 = Untreated, Dark samples; p_2 = Treated, "Sun" samples
p_1 = Treated, Dark samples; p_2 = Untreated, Fluor. samples
p_1 = Treated, Dark samples; p_2 = Untreated, "Sun" samples
p_1 = Untreated, Fluor samples; p_2 = Treated, "Sun" samples
p_1 = Treated, Fluor samples; p_2 = Untreated, "Sun" samples

$n = 300$
$k = 9$
$\alpha_B = \alpha/k = 0.05/9 = 0.0056$

Table 32: Statistical Analysis of Table 15 (Comparisons of the Effect of Acetic Acid Regeneration Treatment on Print Quality According to Print Type - All Samples)

		Rating Comparisons	p_1	p_2	p	s_{p1-p2}	z_{CALC}	$z_{CRIT,0.05}$	difference significant?
p_1 = Clean	p_2 = Oily	better	0.256	0.120	0.188	0.049	2.752	1.96	yes
		same	0.488	0.544	0.516	0.063	0.886	1.96	no
		worse	0.256	0.336	0.296	0.058	1.385	1.96	no

n = 125
k = 1
$\alpha_B = \alpha/k = 0.05/1 = 0.05$

Table 33: Statistical Analysis of Table 16 (Comparisons of the Effect of Acetic Acid Regeneration Treatment on Background Polymerization According to Print Type - All Samples)

		Rating Comparisons	p_1	p_2	p	s_{p1-p2}	z_{CALC}	$z_{CRIT,0.05}$	difference significant?
p_1 = Clean	p_2 = Oily	better	0.496	0.504	0.500	0.063	0.126	1.96	no
		same	0.376	0.424	0.400	0.062	0.775	1.96	no
		worse	0.128	0.072	0.100	0.038	1.476	1.96	no

n = 125
k = 1
$\alpha_B = \alpha/k = 0.05/1 = 0.05$

Table 34: Statistical Analysis of Table 17 (Comparisons of the Effect of Acetic Acid Regeneration Treatment on Print Quality According to Lighting Condition - Samples Aged 2 to 7 Days)

		Rating Comparisons	p_1	p_2	p	s_{p1-p2}	z_{CALC}	$z_{CRIT,0.017}$	difference significant?
p_1 = Dark	p_2 = Fluor.	better	0.260	0.120	0.190	0.078	1.784	2.39	no
		same	0.280	0.520	0.400	0.098	2.449	2.39	yes
		worse	0.460	0.360	0.410	0.098	1.017	2.39	no
p_1 = Dark	p_2 = "Sun"	better	0.260	0.220	0.240	0.085	0.468	2.39	no
		same	0.280	0.540	0.410	0.098	2.643	2.39	yes
		worse	0.460	0.240	0.350	0.095	2.306	2.39	no
p_1 = Fluor.	p_2 = "Sun"	better	0.120	0.220	0.170	0.075	1.331	2.39	no
		same	0.520	0.540	0.530	0.100	0.200	2.39	no
		worse	0.360	0.240	0.300	0.092	1.309	2.39	no

n = 50
k = 3
$\alpha_B = \alpha/k = 0.05/3 = 0.017$

Table 35: Statistical Analysis of Table 18 (Comparisons of the Effect of Acetic Acid Regeneration Treatment on Background Polymerization According to Lighting Condition - Samples Aged 2 to 7 Days)

		Rating Comparisons	p_1	p_2	p	s_{p1-p2}	z_{CALC}	$z_{CRIT,0.017}$	difference significant?
p_1 = Dark	p_2 = Fluor.	better	0.400	0.480	0.440	0.099	0.806	2.39	no
		same	0.440	0.420	0.430	0.099	0.202	2.39	no
		worse	0.160	0.100	0.130	0.067	0.892	2.39	no
p_1 = Dark	p_2 = "Sun"	better	0.400	0.380	0.390	0.098	0.205	2.39	no
		same	0.440	0.520	0.480	0.100	0.801	2.39	no
		worse	0.160	0.100	0.130	0.067	0.892	2.39	no
p_1 = Fluor.	p_2 = "Sun"	better	0.480	0.380	0.430	0.099	1.010	2.39	no
		same	0.420	0.520	0.470	0.100	1.002	2.39	no
		worse	0.100	0.100	0.100	0.060	0.000	2.39	no

n = 50
k = 3
$\alpha_B = \alpha/k = 0.05/3 = 0.017$

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