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Preliminary Study on the Reliability of AFIX Tracker for Lip Print Examination

Kelli E. Edmiston
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**Preliminary Study on the Reliability of AFIX Tracker for
Lip Print Examination**

Kelli E. Edmiston, B.S.

**Thesis submitted to the
Eberly College of Arts and Sciences
at West Virginia University
in partial fulfillment of the requirements
for the degree of**

**Master of Science
in
Forensic and Investigative Science**

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Patrick Buzzini, Ph.D.
Jeffrey Wells, Ph.D.**

Forensic and Investigative Science Program

**Morgantown, West Virginia
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Nikon D90**

ABSTRACT

Preliminary Study on the Reliability of AFIX Tracker for Lip Print Examination

Kelli E. Edmiston

Lip prints have been proposed as a type of impression evidence with similar issues as fingerprints, but with greater scrutiny by the forensic community due to a lack of history in using this type of impression as evidence. A survey of 11 questions about lip print examination was sent to 63 members of the Chesapeake Bay Division of the International Association for Identification (CBD-IAI) to gather opinions from active forensic scientists in determining an appropriate direction for this study. The responses were presented at the spring CBD-IAI 2009 conference to generate more discussion and to achieve greater awareness. A method including glass slides, magnetic black powder with photography and tape lifting resulted. Phase I focused on intervariability with the collection of 300 impressions from 100 individuals. Phase II focused on intravariability. The 49 “best” donors from Phase I were selected for the collection of 6 lip prints on 5 different dates throughout 2 different seasons, fall and winter. In total, 1770 lip prints were collected in this study. In addition to promoting awareness for lip prints, the purpose of this study was to test the reliability of AFIX Tracker, a minutiae based system, for lip print individualization. Reproducible rules of mark-up were established for lip prints based on the author’s classification systems, frequency analyses, and experience with AFIX Tracker for fingerprint examination. Preliminary analysis resulted in the detection of 4 potentially useful “minutiae”, or unique identifying characteristics: bifurcations, diamonds, triangles, and middle horizontals. Each minutiae Type was tested via AFIX Tracker by the analysis of 10 individuals from Phase I. Focus was placed on the number of matched minutiae and match score corresponding to where False Positives (Type I errors) decrease and where False Negatives (Type II errors) increase. As a preliminary study, it cannot be said if all individuals produced different lip prints. In addition, the author cannot say if changes did or did not occur in lip print patterns with change in time. Future analysis will involve a more thorough approach to these issues.

DEDICATION

To victims who may benefit from lip print examination, including persons who may have been wrongfully convicted.

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I take this moment to acknowledge all of those who made this achievement possible.

Thank you West Virginia University's Forensic & Investigative Science Program for having faith in me these past six years while I obtained a Bachelors of Science in undergrad and continued to become a part of the first graduating class obtaining a Master of Science as an Examiner.

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CHAPTER I: Introduction

1.1 Cheiloscopy

The coined term, “Cheiloscopy” of Greek origin, refers to the study of lip prints (1). The importance of cheiloscopy is linked to the fact that lip prints are unique to one person, except in monozygotic twins (1-7). Yet, other sources have claimed lip prints as providing an even greater value of identification, similar to that of fingerprints (6). Overall, agreement lies in the fact that lips, as well as the hard palate, are known to have features that can lead to a person’s identification (1).

Anatomically, lips extend from the lower end of the nose to the upper end of the chin (8) (Fig.1). They are two, sensitive folds composed of skin, bundles of striated muscle, specifically the *orbicularis oris* muscle, sebaceous glands and mucous membrane (1, 8). The vermilion zone is the transitional zone between the glabrous skin and the mucous membrane, which contains no hair or sweat glands, but contains sebaceous glands (8). Philtrum is the mid-line depression that extends from the columella (base) of the nose to the superior edge of the vermilion zone. Commissures are the angles of the mouth where the upper and lower lips meet (8). There are two different kinds of lip covering: skin or mucosa (8). When the two meet, a white wavy line is formed creating the labial cord. Klein’s zone contains wrinkles and grooves that form the lip print, which is where identification is concerned (8).

FIG. 2—Labeled Diagram of the Anatomical Features of Lips (8).

Lips are known to be horizontal, elevated or depressed with the ability to show varying expressions. Particular thickness has been quantified through cheiloscopy. Thickness categories are thin ($< 8\text{mm}$), medium ($8\text{-}10\text{mm}$), thick or very thick ($> 10\text{mm}$), and mixture (8). Thin lips are more commonly found in European Caucasians, thick or very thick lips are common in people of African descent, and a mixture of thickness is more commonly found in Asians. Overall, medium thickness is most common (8).

Similarly to the friction ridge and furrow relationship of fingerprints, lips have creases in the skin corresponding to light, white areas in the print. Raised dark, reddish areas are outlined by those creases. In analyzing lip print impressions, the dark areas are often easier to identify than light areas, which could be due to pressure and movement, amongst other factors (8). Lips may encounter other factors that alter the appearance of lip patterns. These encounters are afflictions such as chapped lips, herpes, melanoma, etc. (8). For example, in a study conducted by Tsuchihashi, one of the subjects caught a cold during the observation period. The shape of the mouth was slightly changed,

however, upon healing, the mouth returned to its original shape with the lip print reassuming its former pattern (8). Therefore, for the most part, from their formation during the sixth week of uterine life, lip grooves have been found to remain unchanged (8). This occurs approximately a month before the development of friction ridge skin for fingerprints (1, 9).

1.2 Limitations and Challenges

Since *Daubert*, the limitations of lip print examinations have been reassessed. Even since *Frye*, has there been general acceptance? What is an expert? When does one become an expert? Other factors to consider include mobility of lips, post-mortem changes, the above mentioned temporary alterations, and the loss of detail from 3D to a 2D image. Simply, it is not feasible to study all lip prints. Likewise, it is not feasible to study all fingerprints, but the difference lies in a strong foundation of history. What does fingerprint history reveal? What can we learn? It is the opinion of the author that one must understand the challenges of fingerprints to understand issues that may arise with lip prints.

As previously mentioned, one cannot study all fingerprints. There are two main assumptions associated with fingerprints. First, fingerprint comparisons require the assumption of permanence over time. Otherwise, what would be the point in comparing them? Secondly, individualization on the basis of friction ridge pattern requires also that the pattern be unique (10). How do we know this is true? An example of the same pattern of friction ridge skin from exemplars of two different fingers has never been published. Such refutable evidence is likely to be published immediately (10).

Moreover, the empirical comparison of fingerprints taken from the same person over large gaps of time has led to the general acceptance of fingerprint identification.

Therefore, uniqueness has been determined inductively.

As an argument, the recent National Academy of Sciences report entitled, “Strengthening Forensic Science in the United States: A Path Forward” stated:

Uniqueness does not guarantee that prints from two different people are always sufficiently different that they cannot be confused, or that two impressions made by the same finger will also be sufficiently similar to be discerned as coming from the same source (10, 11)

Moreover, “an unknown number of identifications are erroneous” (10). Two examples of establishing standards are: the amount and kind of detail required in a latent that makes it useable for comparison, and the amount of agreement between latent and exemplar that ensures an identification (10). The analyst must be aware of their limitations. Consider the following two points:

When you identify someone, you can do it because they are familiar. You do not claim expertise, special training, or that you are using a scientific method... Prints from a scene are unfamiliar. The analyst is able to compare unfamiliar prints because they were trained to follow a scientific method until they could perform in accordance with the standards of the profession. They have become an expert (10).

In spite of our high degree of sameness, the even higher level of difference we possess allows for reliable and often needed methods of distinguishing one person from another. Successful differentiation depends upon an accurate awareness as to which parts of our characteristics catalog are truly common to all and which parts are distinctly individual... Only with reliable knowledge can we devise methods which recognize those features that are the properties of only one person. Only with accurate knowledge can we achieve sufficient precision in that recognition to ensure verifiable protocols, thus establishing a science (12).

Every touch leaves a different version of the friction ridge skin pattern. To identify the latent, the examiner must compare that single, unfamiliar image to a different, unfamiliar

single image (10). The amount of agreement may be sufficient for the analyst to conclude with *certainty* that the latent fingerprint was made by the defendant and could have been made by no other person on earth based on the analyst's *training* and *experience* (10). (Remember, the match can only show the defendant touched the surface at some point in time because age cannot be determined). The accuracy of the method is demonstrated by how well the analyst can sort pairs of fingerprints based on whether each pair shares or does not share the same underlying pattern (10). Reaching a conclusion and then immediately knowing the truth helps improve accuracy since one can learn from mistakes. However, in forensics, feedback is replaced by a scientific, valid method. The analyst may or may not be *100 percent certain*, but they are able to testify with some confidence because of their proficiency in applying the method.

1.3 Purpose

Impression evidence has proven to greatly assist criminal investigations. According to the National Academy of Sciences (NAS) report, the list of impression evidence is long, but some examples include bite marks, markings on bullets and cartridge cases, ear prints, lip prints, toolmarks, some bloodstain patterns, and glove prints (11). Therefore, even the National Research Council acknowledges lip prints as impression evidence. Each evidence type involves the comparison of class and individual characteristics, which could result in either the inclusion or exclusion of an individual source. Fingerprint analysis is by far the most common use of impression evidence. Lip prints have been proposed as a type of impression evidence with similar issues as fingerprints, but with greater scrutiny by the forensic community due to a lack of history in using this type of

impression as evidence. Although lip prints have been studied for over a century, they are not commonly recovered at crime scenes. Lip print identification has been given little acknowledgement.

The purpose of this study is to promote awareness of lip print identification. The intent is not to stimulate a premature use of lip print identification in actual casework, but simply to stimulate research and testing. In fact, the third recommendation of the NAS report states, "Research is needed to address issues of accuracy, reliability, and validity in the forensic science disciplines" (11). The document also discussed the need for research to specifically establish limits and measure performance by saying:

Although some techniques may be too imprecise to permit accurate identification of a specific individual, they may still provide useful and accurate information about questions of classification (11).

Lip prints are not commonly recovered at crime scenes, but perhaps this is due to the lack of protocols dealing with collection, development and analysis. Are crime scene investigators even looking for this type of evidence?

Furthermore, the purpose of this study is to test the reliability of AFIX Tracker for lip print individualization. AFIX Tracker is a fully featured minutiae-based fingerprint and palm print identification system (AFIS/APIS) (13). It is a tool that is compatible with all major livescan devices and is an alternative, affordable solution that tends to rival the more expensive Automated Fingerprint Identification Systems (AFIS) (13). The database can be used to perform searches including, but not limited to palm prints and latent prints. In performing a search, the plotted minutiae are compared with the minutiae records in the reference database based on x, y, and orientation coordinates. The result is a generated score of the likelihood that the search and the prints within the database were

produced by the same finger (13). A candidate list is generated with corresponding descending match scores. However, the top candidate may not always be the correct match. It is up to the examiner to make the final decision. The basic, model components of decisions can be established as follows:

TABLE 1– *Matrix Developed from Actual and Hypothesized Factors with Emphasis on Type I and II Errors.*

MODEL COMPONENTS		
	ACTUAL	
	TRUE	FALSE
YES	T+	F+ (TYPE I)
NO	F- (TYPE II)	T-

TP = True Positive = T+ = Making a correct identification

TN = True Negative = T- = Making a correct non-identification

FP = False Positive = F+ = Making an incorrect identification
[Type I Error: Most Serious]

FN = False Negative = F- = Making an incorrect non-identification
[Type II Error]

It is our duty as forensic scientists to try to eliminate Type I and II errors when possible. Therefore, a goal of this study is to determine where AFIX Tracker is making the above decisions based on the author's defined minutiae mark-up rules and devised database of lip prints. This is not to suggest lip print identification will be up to *Daubert* or *Frye* standards, but it is a step forward towards this possibility.

CHAPTER II: LITERATURE REVIEW

2.1 Pioneers of Lip Print Identification

The following historical outline of pioneers was developed mainly by Caldas, Magalhães and Afonso (1). A summary of the most notable experts and their contributions can be found in Table 2 below.

TABLE 2—*List of Notable Experts and their Contributions to Lip Print Identification.*

DATE	EXPERT	CONTRIBUTION
1902	R. Fischer	Described furrows on red part of lips
1930	Diou de Lille	Developed studies that led to use in criminology
1932	Edmond Locard	Acknowledged the importance of cheiloscopy
1960	Martín Santos	Suggested simple & compound groups with eight subtypes
1972	M. Renaud	Studied 4,000 lip prints & confirmed singularity
1974	Suzuki & Tsuchihashi	Developed new classification system

Lip prints have been under scrutiny for over a century. In 1902, Fischer, an anthropologist, was first to describe the biological features (1, 4). However, it was not until around 1930 when Diou de Lille developed studies which led to lip print use in criminology (1, 14). Within two years, Edmond Locard acknowledged the importance of cheiloscopy (1, 14).

Later, lip print classification systems developed. In the 1960s, Martin Santos suggested the fissures and criss-cross lines in the lips could be divided into simple and compound groups, which could be further divided into eight subtypes (1, 15, 16). Simple

groups referred to characteristics formed by only one element, which could be a straight line, a curve, an angular form, or sinusoidal. Compound groups were those formed by several elements with bifurcated, trifurcated and anomalous being mentioned (1, 15).

In 1972, Renaud studied 4,000 lip prints in support of lip print singularity (1, 17). Lips were studied in halves (left and right). Every groove, according to its form was assigned a number. A formula was then devised using capital letters to describe the upper left (L) and right (R) sides, and small letters to classify each groove. Conversely, the lower lip was considered the other way around, using capital letters to classify grooves and small letters to separate left from right sides (1, 17). The following table provides a summary of the Renaud classification system (Table 3) (1).

TABLE 3—*Renaud Lip Print Classification.*

CLASSIFICATION	GROOVE TYPE
A	Complete Vertical
B	Incomplete Vertical
C	Complete Bifurcated
D	Incomplete Bifurcated
E	Complete Branched
F	Incomplete Branched
G	Reticular Pattern
H	X or Coma Form
I	Horizontal
J	Other Forms (Ellipse, Triangle)

In 1974, two years after Renaud, Suzuki and Tsuchihashi developed a study which resulted in a new classification system (1). Their study involved the lips of 107 Japanese females with an age range from 20 to 36 years (16). They unexpectedly found in the course of the study, a groove, rather than a wrinkle pattern of the lips (16). In addition,

their study was conducted over a long period of time allowing the authors to confirm not only lip print singularity, but also lip response to trauma. In fact, the authors observed that after healing, the lip pattern was equal to that before the injury occurred (1, 6, 16). The following table provides a summary of the Suzuki and Tsuchihashi classification system (Table 4) (1).

TABLE 4—*Suzuki and Tsuchihashi Lip Print Classification.*

CLASSIFICATION	GROOVE TYPE
Type I	Complete Vertical
Type I'	Incomplete Vertical
Type II	Branched
Type III	Intersected
Type IV	Reticular Pattern
Type V	Irregular

In another study published by Suzuki and Tsuchihashi entitled, “New Attempt of Personal Identification by Means of Lip Print”, lip prints were collected from 280 individuals consisting of 150 males and 130 females with an age range of 6 to 57 years (16). Lip prints were also obtained from 18 pairs of uniovular (identical) twins, aged 12 to 13 years of both boys and girls. The lip prints were directly collected from the lips, as fingerprints through a “Finger Printer”, which was observed under magnifying lenses and traced onto cellophane (16). Lip prints were recorded in a form similar to a dental formula with vertical lines defining left and right sides of lips and horizontal lines defining upper and lower lips (16). The results were the following: 1. No lip print manifested the same pattern in the investigation of 280 individuals; 2. Lip prints of twins were extremely alike with their characteristics being inherited from either one of their

father or mother; 3. The authors intended on conducting a longitudinal study in the future by taking lip prints of the same individuals every month to clarify if patterns remain unchanged throughout life (16). They proposed the remaining problems of age and seasonal influences and the need of such issues to be solved in the near future (16).

Tsuchihashi alone conducted the following study. 1364 healthy volunteers, including 757 males and 607 females from Japan with an age range of 3 to 60 years were chosen. Some subjects were used in the investigation to study the existence of twin hereditary factors. Groups were comprised of child A, child B, and both parents resulting in a total of 53 groups (212 people) of twin families. Tsuchihashi understood the importance of data recording for the study. Therefore, he used various methods of taking impressions and preparing casts with different impression materials used in dentistry. He settled on the following method due to the mobility of human lips including strength and pressure factors altering accuracy of lip prints taken (6). Life-size photographs were obtained. Special finger printer (no-ink by Hollister Co.) paper was applied directly to the lips to record the pattern of the lip print. The lip prints obtained were traced onto cellophane paper and examined with a magnifying glass. The type of lip print was then determined and entered according to the dental formula: horizontal line was drawn to distinguish the upper from the lower lip and a median line to divide the left and the right sides. The classification Types were recorded in its respective quadrant with respect to the above classification system (6).

Tsuchihashi's results consisted of the following. Close inspection revealed the lip print did not consist simply of one Type alone, but appeared as a mixture of varying Types. Tsuchihashi stated, "It is a matter of great consequence whether lip prints are

absolutely dissimilar or not. It was found that no two lip prints were identical. It is therefore considered that one would be justified in saying that each of the 1364 subjects has his or her own lip print” (6). For each pair of twins, the lip prints were nearly the same, but not absolutely identical (6). Also, the twins frequently showed patterns extremely similar to those of their parents. The permanence of lip prints was also examined by 7 adults (3 males and 4 females). They were recorded routinely once a month for 3 years. No change was observed during this time (6).

Similarly, two more classification systems were found and noted as the Dominguez and the Afchar-Bayat classification systems. The former system was based on Suzuki and Tsuchihashi’s system above (Table 4). A slight variation was found in the grooves classified as Type II. Branched grooves were found to divide upwards in the upper lip and downwards in the lower, as reported by Suzuki and Tsuchihashi, but some grooves, the so called II’ Type were found to branch the other way around (1, 18). The latter system was dated from 1979 and is based on a six-type groove organization (1, 19). The following table provides a summary of the Afchar-Bayat system (Table 5) (1).

TABLE 5—*Afchar-Bayat Lip Print Classification.*

CLASSIFICATION	GROOVE TYPE
A1	Vertical and straight grooves, covering the whole lip
A2	Like the former, but not covering the whole lip
B1	Straight branched grooves
B2	Angulated branched grooves
C	Converging grooves
D	Reticular pattern grooves
E	Other grooves

2.2 Recent Studies of Lip Print Identification

Many, if not most, of the recent studies use the classification system proposed by Suzuki and Tsuchihashi. A 2009 study in India by Saraswathi, Mishra and Ranganathan is no exception. They studied 100 healthy individuals comprising of 50 males and 50 females with an age range of 18 to 30 (20). The lips were cleaned before brown-colored lipstick was applied. Over the lipstick, the glued portion of cellophane tape was placed on the subject's lips, extracted, and then placed on white chart paper. The resulting image was visualized by a magnifying lens. They concluded that no two or more individuals had a similar type of lip print pattern (20). Specifically, intersecting patterns [Type III] were found to be most common in both upper and lower lips, both among males and females having 39.5% and 36.5%, respectively (20). The least common pattern found was the reticular [Type IV] seen in 11.0% males and 13.0% females (20). Of all the lip prints obtained, 10.25% were smudged and spoiled with poor quality resulting in their exclusion from the study. The examiners claimed this problem largely to be from the presence of prominent facial hair from men (20).

Another 2009 study considered Suzuki and Tsuchihashi's classification system. The sample size included 300 healthy North Indian individuals with an age range of 18 to 65 from Uttarakhand, India. Males and females were equal in number. 50 of the 300 individuals (25 females; 25 males) were selected for studying the permanence of lip prints. Lip prints were initially taken and later retaken one year later. The volunteers applied lipstick to their clean lips. Bond paper was fixed to cardboard, which was directly applied to their cosmetic lips. The paper was then removed from the cardboard and folded along the length to be pressed between the two lips. This ensured the

transition zone was also captured in the print (21). Lip prints were recorded in a way resembling a dental formula, similar to those used in dental clinics, and similar to Suzuki and Tsuchihashi (Table 6) (6, 21).

TABLE 6—*Bindal's Dental Formula for Classification.*

Right upper Quadrant (Q1)	Left upper Quadrant (Q2)
Right lower Quadrant (Q4)	Left lower Quadrant (Q4)
II I	I II
III II I	I I'

By examination, lip prints showed combinations of patterns to be present in all quadrants. The authors claimed no two lip prints of individuals' matched with each other (21). Given the 300 individuals, a total of 1200 quadrants were studied. The most frequent pattern in the males studied was Type II [Partial length groove] (60.5%) and the least observed pattern was Type III [Branching] (29.7%) (21). The most frequent pattern in the females studied was also Type II (66.8%) and the least observed pattern was also Type III (27.0%) (21). The observations revealed no change in the lip print patterns with change in time. The authors' conclusions stated, "Since lip prints are different in every individual and does not change with time so it can also be used as a method for identification" (21).

In Japan in 2005, cadavers were donated to clarify postmortem changes to lip prints to determine whether lip prints obtained from the deceased have similar applications to

those of living subjects. The study also used methods of Tsuchihashi for groove classification. The sample size was 20, including 11 males and 9 females with an age range of 39 to 91. First, lip impressions were obtained less than 24 hours from the time of death and secondly, 48 hours after fixation with 10% formalin. Similarly to the above Saraswathi study, lipstick was applied followed by cellophane tape with the resulting impression being fixed to white paper. Measurements were compared by using the following equation to determine whether enlargement or shrinkage had occurred (Table 7) (22).

TABLE 7—*Utsuno's Enlargment or Shrinkage of Lips Equation.*

$\frac{\text{Post-fixation measurement (mm)}}{\text{Pre-fixation measurement (mm)}} \times 100$

Similarly to the above Bindal study, lip impressions were divided into four areas. Samples in which more than one of the four areas of lip impression demonstrated matching lip groove shape and pattern, were regarded as identifiable (22). The authors concluded no significant enlargement or shrinkage occurred. On comparison of lip prints, prints taken before fixation matched those taken after fixation 6 of 20 cases, representing a 30.0% identification rate. According to the authors, with exception of situations in which there is considerable injury or deformity, the results of this study suggest that clear and identifiable lip prints can be obtained if taken less than 24 hours after death (22).

In the same year, Vahanwala, Nayak, and Pagare performed a study to ascertain whether lip prints behold potential for the determination of sex of an individual from the following configuration derived from Vahanwala-Parekh (Table 8) (23).

TABLE 8—*Vahanwala-Parekh's Results.*

Lip-pattern	Region of occurrence	Predominantly seen in
a. Type I & Type II	1st quadrant [right upper lip]	Female
b. Type II	2nd quadrant [left upper lip]	Male
c. Type III	Never occurs in lower lip	If so then only in Male
d. Varied patterns	In all quadrants	Male
e. Same [alike] patterns	In all quadrants	Female

50 healthy subjects including 20 males and 30 females with an age range of 19 to 29 were chosen (23). Lipstick was applied, collecting the impression on bond paper. Given the above configuration and with respect to Suzuki's classification system, all of the 30 females were correctly identified as females by one of the researchers. Of the 20 males, 16 were correctly identified as males, 1 incorrectly as a female and 3 were inconclusive (23). The authors reasoned out the mistake by clarifying that trends of both the sexes were prevalent at the same time and variant Types in all quadrants made decision making for the researcher a little difficult (23).

In 2007, Suzuki and Tsuchihashi's ideas were considered but not enforced by Coward, a private dental practitioner from the United Kingdom. Coward considered the classification to be too complicated and confusing (24). Instead, Coward's study was confined to major pattern types (i.e. linear, reticular, and mixed) and the fine pattern details. However, similarly to Vahanwala-Sonal in the above source, the determination of sex was attempted by Coward. 85 individuals including 41 females and 44 males were

volunteers in the study. A protocol was devised based on a transparent overlay system and contact prints enhanced by powder dusting. The method of Suzuki and Tsuchihashi was upgraded with the use of computerized image gathering and enhancement to avoid the vagaries of tracing. Lip prints were collected by the direct contact of lips onto a recording medium held in the sagittal plane. Prints were enhanced by dusting with K9 Magneta Flake fingerprint powder. The developed impression was digitally recorded via a computer scanner. Once the image was captured, enhancement was achieved using Adobe Photoshop 4. To enable comparison of each successive set of prints, one good quality print was collected from each subject early in the study, which was scanned and enhanced in the same manner. This produced an overlay matching in size to the hard copies made earlier. Lip prints were recorded monthly for a total of six collections and 326 prints. The initial series of prints were transferred onto clear acetate for use as the standard with which subsequent prints were compared. The later series were printed conventionally onto paper (24).

The following features were individually examined to determine if they could provide relevant data: general appearance, facial contours and profile, philtrum, chin, facial hair, pathologies and peculiarities, print surface, vermilion patterns, examination and comparison, inter-examiner variability and intra-examiner variability. The author concluded there is a considerable variation in the lip's overall shape (24). Furthermore, it was explained how some of these characteristics may vary over time due to muscle posturing or recording conditions but the overall shape should be recognizable and help to distinguish one from another (24). Coward's observation for sufficiently large surfaces was that most people will leave some print of nose, philtrum, upper and lower

lip and possibly chin. Therefore, the width and appearance where the philtrum joins the upper lip may also provide identification data (24). According to Coward, in some cases, an anatomical feature is so distinct that it may be regarded as a characteristic in its own right (24). In fact, the presence, distribution and density of hair follicles may provide guidance towards the sex of the subject (24).

In regarding examination and comparison, numerical scores were derived based on the following: (a) general appearance, matching of “size” and “shape”, 2 for “good”, 1 for “fair”; (b) contact line shape, 2 for “good”, 1 for “fair”; (c) number of notches matching; and (d) number of pattern matches. These scores were then totaled. Based on Cowards research, eight was determined to be the significant number when counting points of concordance for this study. Discrepancies were found with subjective decisions regarding the anatomic features (24). 140 prints were of sufficient quality to study the notches. In studying pattern type and coarseness, only 79 individuals were available due to the other individuals failing to leave a visible print and/or impossible to determine their pattern type. Notably, Coward made the following comment in studying print surface, “It was noticeably early in the study that the quality of prints deposited on the glass slide varied enormously between individuals and that, in many cases, this quality of print was consistent” (24). Coward continued to explain the surfaces deposited were categorized to be either lipstick, wet, dry, or poor. In fact, lipstick was the most frequently encountered variant of the print surface (24). Lipstick was detected first as a coloured deposit on the slide and secondly, when dusted, the plain surfaces attracted the powder, obliterating large areas (24).

For the determination of sex, facial hair was studied. Individual prints were considered at greater magnification to record the presence or absence of hair. As a result, 90.0% of female subjects showed visible facial hair, which was extremely consistent over successive prints. Only 31.0% of male subjects showed facial hair, and of these, only 4 were present 4/6 months and the remainder mainly single occurrences (24).

Many of the above recent studies have utilized lipstick for the retrieval of lip impressions. In Spain in 2002, a study provided awareness about traditional lipsticks producing easily identifiable lip prints, but recently popular long-lasting lipsticks can be formulated to be invisible, requiring reagents that are more sensitive than conventional materials to locate and develop the prints (25). Specifically noted, lipsticks have different compositions with oil content being reduced to a minimum for long-lasting lipsticks (25). This study analyzed the effectiveness of reagents that are generically called lysochromes (Sudan III, Oil Red O, and Sudan Black). Lysochromes are compounds that contain a portion that dissolves when in contact with fat (lyso) and another that is responsible for color (chrome) (25). Specifically, this study compares the effectiveness of the lysochromes to the fingerprint red (Dragon's Red), black, and silver metallic conventional powders as well as to Ninhydrin in developing latent lip prints from long-lasting lipsticks on porous paper and cloth surfaces. 10 volunteers applied lipstick and waited 5 minutes for fixation. Lip impressions were made on tissue paper and white cotton fabric for 3 seconds. The latent lip prints were developed at intervals ranging from 1 to 40 days. Both powder and solution reagent forms were utilized. Application of the powder was continued and extended until the print could be seen clearly. Application of solution involved complete submersion. The authors claimed the

quality of the development depended on the surface type and age of the latent lip print (25). For instance, on tissue paper, neither recent nor older prints were developed using conventional powders, but the lysochromes powders and solutions produced high quality prints up to 20 days old. On white cotton fabric, conventional developers were used but their effectiveness diminished on older prints. Whereas, lysochromes produced good quality prints up to 40 days old. Specifically, the use of Ninhydrin produced no reaction. Therefore, the authors concluded lysochromes are a highly useful group of compounds (powder and solution forms) for locating and developing recent as well as older latent lip prints (25).

More recently, Spain in 2006 provided another study in which lysochromes were tested for their effectiveness in developing invisible lipstick-contaminated lip marks on human skin (26). The authors, Navarro, Castelló, and Verdú, first provided caution that human skin is a difficult surface for developing this kind of evidence because the same organic elements that generate the prints, and are used for detection, can also be found on the skin interfering with development (26). 17 cadavers of ages 35 to 75 years were used in this study. Lipsticks were spread on a mould, followed by a 3 to 4 minute fixation. The mould was pressed on the corpse's skin (right side of neck and anterior region of forearm). To determine the possible variations on the reagents' effectiveness, the cadavers were kept in non-refrigerated, yet cold room (26). Both the date and cause of death were variable. First, a visual examination occurred with UV light and a Bluemaxx alternate light source. Second, Reagents (Sudan III, Oil Red O, and Sudan Black) were applied in powdered form. Third, the surface was washed with distilled water, eliminating excess reagent allowing better visualization of the print (26). The initial

visual examination located visible lip marks before the application of lysochromes. Specifically, lip marks from protective lipsticks were visualized more easily than permanent lipsticks. A positive development for all lip marks was obtained. According to the authors, this meant the shape and lip outline could be seen with some lip lines and wrinkles (26). Sudan Black produced the best development. In conclusion, the authors stated, “The possibility of using these reagents on latent lip prints produced without lipsticks (“normal” lip marks) should be studied” (26).

In a follow-up study, Castelló and Verdú tested the usefulness of fluorescent reagents on both multicolored and dark colored surfaces (27). The study compared the usefulness of two kinds of fluorescent reagents: Yellowescent Fluorescent Latent Print Powder and Nile Red for developing latent lip prints older than 1.5 years on multicolored surfaces. The reagents were used in powder form and luminescence was observed by an alternate light source and ultraviolet light. 6 volunteers applied protective and long-lasting lipstick and waited 1 minute for fixation. Lip impressions were made on multicolored paper using sustained pressure for 3 seconds. Collections occurred on successive days until a sufficient number of prints was obtained (27). Control samples were created due to the potential issue of Sudan Black having contrast problems with multicolored surfaces. The latent prints were developed with the respective powders. Developing quality was scored as follows (27):

- A high quality development (+++) indicates that the shape and the outline, as well as the lip lines and wrinkles can be easily noticed.
- A low quality development (+) implies the shape and the lip outlines that are readily noticed, but without lines and wrinkles.
- A medium quality development (++) falls in-between the above two development descriptions with only partial notice of lines and wrinkles.
- No development (-) and no contrast was also noted.

Nile Red produced high quality (+++) developments for both recent and older lip prints. Sudan Black was a very effective reagent (++) for old prints deposited on light color porous surfaces, but had no contrast with darker surfaces. Yollowescent Fluorescent was less effective for older prints showing low quality (+) and no contrast (-) developments as time progressed (27).

A study specifically involving Nile Red was found by the same two authors, Castelló and Verdú with the addition of Alvarez-Sequí, also from Spain. They used latent lip prints from protective and permanent lipsticks that were available at the laboratory, which had not been used in previous trials. Specifically, they were over 1 year old on porous surfaces particularly difficult to develop such as colored paper napkins, colored cotton and satin cloths (28). Prints were made by allowing a 5 minute lipstick fixation followed by 3 seconds of pressure application to the substrates. The prints had been left out on a table without any kind of protection. The developing was tried with the reagent in powder and as a solution with ethanol (concentration 1 µg/ml) (28). A brush or piece of cotton was used for application followed by a UV light and Bluemaxx alternate light source. All prints were considered to have good quality development (can notice the shape and the outline, as well as the lip lines and wrinkles) and therefore, useful for identification, according to the authors (28).

The same researchers: Castelló, Verdú, Alvarez-Sequí with the addition of Miquel Feucht wrote another article in Spain. Their study reinstated the importance of invisible lip prints by current lipsticks, which could be overlooked at crime scenes (29). The study used black and white colored ceramics, green-colored glass, white cotton fabric and white paper as mediums. Lip prints were left to dwell for different periods and were later

developed using aluminum powder, cobalt oxide powder and magnetic powder. The results showed that identifiable lip prints can be obtained up to 30 days after being produced (29).

Spain and Japan have largely contributed to lip print identification thus far, but credit should also be given to Korea. A study was found written by 13 authors with the aim of finding out useful parameters from the image analysis of lip wrinkles that is affected by lipstick application (30). The authors made the following statement, “It has not been clearly revealed whether the structural or functional mechanism responsible for lip wrinkle are because of the aging process or innate determining factors yet” (30). The change of wrinkle-related parameters was studied on 50 Korean women who used a lipstick containing asiaticoside extract from *Centella asiatica* as an active ingredient for reducing lip wrinkle (30). First, 20 healthy females with an age range of 22 to 34 were selected. They were asked not to use any lipstick for 7 days before starting the experiment. An apparatus fixed the head to avoid movement, in-front of which, a digital camera was placed to capture the defined area of lips to be investigated. The digital images were evaluated for color tone after the lipstick application. The authors then measured the saturation value (1.2μm length) of 10 wrinkle areas and 10 non-wrinkle areas per person. Photographs were also taken 1 and 2 hours later to study spread phenomenon. Secondly, 50 healthy women with an age range of 20 to 27 years participated in the clinical efficacy study. This required the application of lipsticks twice a day for 8 weeks. Digital photographs were taken before, after 4, and 8 weeks of application of lipsticks. The overall lip status was represented by both the number and the depth of the wrinkles and was visually graded according to the following five-point

scale by 3 dermatologists: 5 points (very severe), 4 points (severe), 3 points (medium), 2 points (slight) and 1 point (minimal). The final score was determined by the average sum of the depths and numbers.

From the digital image analysis technique, wrinkles were easily recognized by the difference of saturation values (30). The wrinkle-improving lipstick was able to reduce the variability of line profile, spread phenomenon and saturation deviation, which enabled lip coloring to be more evenly applied (30). However, the authors stated, “Wrinkles, in general, develop during the aging process but at present it cannot be confirmed whether the aging process alone is the major determinant of lip wrinkles or not” (30). In addition, the authors did see many younger persons who had exceptionally deeper furrows than older persons (30).

2.3 Court Cases Involving Lip Print Identification

The following case is currently the *Mayfield* of lip print identification (31). The following facts are extracted from the Appellate Court of Illinois’ Second District’s report (32): On December 18, 1993, Patrick “Pall Mall” Furgeson was shot and killed outside the Burnham Mill apartment complex during an apparent robbery attempt. According to the forensic pathologist, Pall Mall died from a gunshot wound to the abdomen and he exhibited an injury to the back of the head, caused by blunt-force trauma. Approximately 1 hour after the incident, a responding officer arrived at the scene and collected the following evidence: 12-gauge “sawed-off” shotgun with spent cartridge in the magazine, a pair of black nylon hose, a pair of work gloves, and a roll of duct tape.

In addition, the investigator noted the items were dry but the ground was wet, indicating the items had been placed there recently (32).

Defendant Lavelle Davis, Raymond Mims and Kari “Major Julian Hill” Brown were charged and tried in separate proceedings. The State’s theory of the case was that the three men borrowed a car and waited for Pall Mall to arrive at the apartment where Raymond lived with his girlfriend, Sharlet Clements. Pall Mall arrived and told Clements he was responding to a page from Major. Pall Mall left the apartment, walked around the side, and ran into mask-wearing Davis and Mims. Allegedly, Davis told Pall Mall that the encounter was a “stick up” and struck him in the back of the head with the shotgun. Mims choked Pall Mall from behind and the shotgun went off when it was pointed at Pall Mall’s stomach (32).

Note, the State did not produce physical evidence linking the defendant to the shotgun, the hose, or the work gloves that were discovered at the scene. However, over the defense counsel’s objection, the State introduced testimony that lip prints found on the duct tape matched Davis, the defendant (32). The State also attempted to show that Clements witnessed the crime and could identify Davis as being the shooter, but Clements’ inconsistent statements and ambiguous testimony led to a mistrial in October of 1996 (32). A second trial resulted. This time, Clements believably identified Davis as the shooter (32). The jury found Davis guilty of felony murder, attempted robbery, and armed violence (32). On July 25, 1997, the trial court imposed a 45-year prison term for the felony murder and two concurrent 10-year prison terms for the other convictions (32).

Davis filed a direct appeal by presenting several arguments in support of reversing the convictions. Some of the arguments are quoted as the following (32):

Because lip identification has not been determined by any other court to be scientifically reliable under the Frye standard [Frye v. United States, 293F. 1013 (D.C. Cir. 1993)], and because the identification method was not reliable in this case, the trial court erred by allowing such testimony to be admitted.

Where the only physical evidence to link [defendant] to this offense was unreliable lip print identification from a roll of duct tape found near the scene, and the State's only other evidence came from an incredible 'eyewitness' who gave multiple statements and committed perjury, the defendant was not proven guilty beyond a reasonable doubt.

Trial counsel's lack of preparation, failure to attend multiple court hearings, failure to cross-examine, and failure to ask for Frye hearing with respect to the lip print evidence rendered him ineffective and substantially prejudiced the outcome of this case.

Davis also argued that his convictions of attempted armed robbery and armed violence violated the one-act, one-crime rule. As a result, On May 12, 1999, his one-act, one-crime ground argument was successful, but the other arguments were rejected (32).

On April 5, 2000, Davis petitioned for relief under the Act. Davis, the defendant alleged the following arguments (32):

The trial counsel was ineffective for failing to investigate and properly prepare this case for trial.

Counsel failed to communicate with him adequately.

Counsel's ill health prevented him from presenting an adequate defense.

Counsel failed to challenge the State's lip-print evidence adequately.

Trial counsel failed to locate any expert who could testify for the defense regarding the unreliability of lip print evidence.

Trial counsel was ineffective for failing to investigate his alibi that he was in Chicago at the time of the offense.

Trial counsel should have impeached Clements, the State's main identification witness, with two letters she had written and her plea agreement.

On June 9, 2005, the trial court heard the petition. Leanne Gray, an Illinois State Police lab forensic scientist, testified that she specialized in latent print examination (32). She examined the roll of duct tape discovered at the scene and found an upper and lower lip print on the first 6 to 8 inches of the tape's sticky side (32). Gray photographed the impression. She testified that lip prints, like fingerprints and other impression evidence, are unique and can be used to positively identify someone (32). Gray took standards of the defendant's lips by using the sticky side of duct tape and lipstick on paper. Gray performed a side-by-side comparison of the standards and the photograph for a duration of 1.5 months, focusing on the lower part of the lower lip (32). Gray then mailed the photograph and standards to McKasson, a Southern Illinois forensic lab scientist, specialized in document examination. Gray later met with McKasson to conduct additional comparisons. They concluded that the defendant was the source of the lip print (32). This resulted in McKasson providing testimony of finding at least 13 points of similarity between a standard and the photograph (32). He also admitted that part of the latent print on the duct tape was not suitable for comparison. The lip print testimony of Gray and McKasson was the only physical evidence linking Davis to the murder (32).

Also at the hearing on the petition, Andre Moenssens and Michael Sinke, both experts in fingerprint identification, were called to testify on behalf of the defendant (32). Moenssens argued that lip print identification is not recognized as an accepted science. His research had disclosed no scientific studies that had conclusively established the accuracy and reliability of lip print identification (32). He further stated that there are no

accepted practices within the forensic science community regarding the methodology for performing lip print identifications. Moenssens believed McKasson lacked the education, training, and experience to conclude that lip prints are unique (32). He also disagreed with Gray's position that lip print comparison is a known and accepted form of scientific comparison and that the Federal Bureau of Identification believes it as a positive form of identification (32). Sinke explained his history of experience with fingerprints and concluded after comparing the standards to the photographs that one could not say to a degree of forensic certainty that the questioned lip print and the known lip print were made by the same person. He found a discrepancy between the questioned print and the known print (32).

Bastianoni, Davis's trial counsel, had to testify by video-recorded deposition. He stated that at the time of the deposition, he did not possess the defendant's file because he discarded it (32). Bastianoni had Parkinson's disease and was on the verge of retirement working out of his home. He recalled missing court dates and requesting continuances in defendant's case because he was sick. Bastianoni recalled that the lip print evidence was the only physical evidence against the defendant, and his trial strategy was to exclude the State's expert testimony or at least undermine its credibility. He could not recall whether he discussed with the defendant the possibility of hiring an expert, but he did recall that the lip print evidence was mentioned 39 times during the opening statement and closing argument (32). Bastianoni concluded that the outcome of the trial might have been different if the lip print evidence had been excluded (32).

Approximately 9 months after the trial court heard the petition, approximately 72 months after Davis petitioned for relief, and approximately 146 months from the incident,

on March 7, 2006, the post-conviction court entered a 22-page order granting the defendant's petition. The court largely found that Bastianoni's representation was deficient and that the cumulative effect of his errors was prejudicial (32). The post-conviction court vacated the felony murder conviction and ordered that Davis be remanded to the sheriff for further proceedings. The State timely appealed (32).

The next case report was explained by pioneers Suzuki and Tsuchihashi in their article, "New Attempt of Personal Identification by Means of Lip Print" (16). An anonymous letter was mailed to the general director of the Tokyo Metropolitan Police Department. Two lip prints were located on the address side of an envelope containing a letter threatening to blow up the Metropolitan Police Headquarters. An immediate search resulted in two suspects being arrested with a great amount of explosives being confiscated. The Metropolitan Police commissioned the identification of the lip prints to the Department of Forensic Odontology of Tokyo Dental College. Upon examination, the suspects were excluded as donors of the lip prints (16).

In addition, Suzuki and Tsuchihashi in their article entitled, "Two Criminal Cases on Lip Print", described the above case with fewer details along with the following case, which reads as follows: "A woman's underwear was scattered with lip marks, and some money was missing. In this case a lip print study was used to definitely identify a criminal, and also avoided the unjust accusation of an innocent person" (33).

The final case of discussion was published in the *Journal of Forensic Identification* in 1991, which of important note; this was before the above *Davis* case and the renowned *Daubert* case of 1993. The article is entitled, "Lip Print – Another Means of Identification" and was written by Williams, an examiner from the Latent Fingerprint

Section of the Federal Bureau of Identification in Washington, D.C (34). Williams wrote, “Lip prints are similar to fingerprints, palm prints, and footprints, in that individual characteristics are used for identification” (34). He continued to say,

All lip print identifications seen by the author have been made utilizing only the major white areas of the prints as characteristics. The white areas on the unknown lip print are matched with those on the known lip print, much as friction-ridge characteristics are used in fingerprints, palm print, and footprint identifications (34).

The author claimed to have compared fingerprint ridges for over 30 years and therefore finds the dark areas of lip prints are more easily located and readily defined than the white areas. The following figure is a reproduction of a chart of a lip print identification made by Williams (Fig. 2).

FIG. 2—Charts of FBI Williams Lip Print Identification (49).

In Figure 2, Williams used the white areas (points #8 and #14) and dark areas (remaining points) (34). Also mentioned, the FBI's Latent Fingerprint Section utilizes this same method for the identification of infants' footprints (34). Furthermore, Williams noted the importance of collecting several "sets" of lip prints. He stated,

Using the author's method of comparison, it is noted that many times individual prints within a "set" cannot be identified with each other. This is due to the flexibility of the lips, the amount of transfer medium, the movement of the lips during the recording, and the amount of pressure applied and the position of the lips. Therefore, several "sets" consisting of numerous prints are necessary (34).

In Williams' conclusion he said, "It is the position of the FBI that lip prints can be used as a positive means of identification" (34). He also added that items on which visible lip prints are discovered or which could bear lip prints should be preserved for a lip print examination.

Finally, Williams admitted to using lip print identification in two cases and in each case, the identification resulted in the subject being convicted (34). One of the cases involved a male bank robber who used female disguises including lipstick. The FBI was misguided, assuming a female bandit (34). The robber was therefore successful in several other bank robberies while wearing this disguise. However, while robbing a bank in 1979, the robber ran into an exit door and left his lip print on the glass. The FBI office submitted photographs and lifts of the lip print. The lip print was identified in 1980, solving the 1979 robbery and several others. This robbery was marked the first time an individual was positively identified through lip prints by the FBI (34). The other case involved the introduction of illicit drugs into a prison. Figure 2 is a reproduction of the charts made for this specific case for court testimony purposes. However, "lip print testimony in this case was not given, inasmuch as the defense stipulated" (34).

CHAPTER III: MATERIALS AND METHODS

3.1 Survey

This study was guided by members of the Chesapeake Bay Division of the International Association for Identification (CBD-IAI). A Microsoft Excel spreadsheet was created with the following headings: Agency, Name, Position, Address, and E-mail. 127 rows were completed. On October 19 - 21 of 2008, a survey of 11 questions (Appendix A: Table A.1) was sent to 63 members acting as a representative of their agency via e-mail (Appendix A: Table A.2). On March 10, 2009, a second, reminder e-mail was sent to unresponsive agencies (Appendix A: Table A.3). The responses were gathered to determine an appropriate direction for research with all of the provided information (examiners, agencies, etc.) remaining confidential. Formal permission would be requested before a specific case or situation would be addressed publically.

3.2 Sample – Phase I: Intervariability

Glass slides (Fisher Scientific - Precleaned, Catalog No. 12-550C, Size: 75 X 50 X 1mm, Quantity: Approx. ½ gross, 71710507) were washed with antibacterial soap (Equate antibacterial liquid soap 40 Fl oz, SL6982B) and dried with paper towels to avoid wet spots. 100 volunteers provided 3 impressions each, consecutively. Volunteers included both male (42) and female (58) university students and faculty. The glass slides were labeled with a number (1-100) corresponding to the volunteer and a letter (A-C), corresponding to the 3 impressions. Both the upper and lower lips were captured simultaneously by allowing the non-treated lips to come directly into contact with the glass in a parallel fashion for 2-3 seconds with medium to heavy pressure. The latent

impression was developed with magnetic black powder (Lynn Peavey Company - 1 oz. 219053-30009) and a magnetic wand (Evident - Item #1004). Photography was performed using Ez Doc 2.0 v.1.0.122 program (Mideo Systems Inc., 2008), AF Micro Nikkor camera (1000ppi) with 60mm lens (Nikon, Japan), and Mideo Systems Inc. camera stand (KFB, Germany). All photographs taken had the following properties: 100ms aperture exposure, 1.00 gain, 1040 offset, oblique lighting, 27 inch working distance, white contrasting background, with a level scale, and grayscale manipulation saved as a .TIF file. White, fingerprint lift backing cards (Lightning Powder - 3" X 5" Re-Order #1-2501) were cut in half with scissors, creating two substrates for two different lifts. Lifting tape (Forensic Source - LPC 2" clear tape 1-1406) was carefully applied to the powdered impression, avoiding air bubbles, and pressed securely to ensure full contact. The lifting tape was removed evenly and carefully placed on a cut-in-half backing card, avoiding air bubbles. Excess tape was removed. The lift was labeled to correspond to the glass slide from which the impression originated. Used glass slides were washed with the antibacterial soap and dried with paper towels to avoid wet spots for future collections. Phase I photographs were examined. 10 volunteers (10.0%) were thrown out of the study based on quality (Appendix B: Figure B.1). Quality was assessed for the purposes of minutiae detection via AFIX Tracker. Issues of quality were hypothesized to arise from not enough pressure and too much moisture. 10 new volunteers were selected as replacements, resulting in a collection total of 300 lip print impressions for Phase I.

3.3 Sample – Phase II: Intravariability

Phase I photographs were examined. The 50 “best” donors of lip prints were selected to participate in Phase II. “Best” donors included those volunteers who provided lip impressions of high clarity and/or detail. Unplanned, the chosen donors were of a 50:50 ratio of males to females. 49 volunteers provided 6 impressions each 5 different times. Due to uncontrollable circumstances, the 50th volunteer, a male donor, could not be collected during all 5 collection dates and was therefore thrown out of the study. The collection dates were the following: 10/19/09, 11/02/09, 12/01/09, 01/11/10, and 01/25/10, which included fall and winter months to account for seasonal changes. The 50 volunteers were scheduled a specific day of the week during the 2 weeks following the collection date based on their availability (Appendix C: Table C.1). The same collection schedule was kept for all collection dates. The glass slides were labeled with a number (1-50) corresponding to the volunteer and a letter (A-F), corresponding to the 6 impressions. Lip print collection was performed in the same manner as Phase I. However, once the lift was created with proper labeling corresponding to the glass slide from which the impression originated, the back of the lift was stamped with the appropriate beginning collection date (i.e. 10/19/09, 11/02/09, 12/01/09, 01/11/10, or 01/25/10). Phase II resulted in a collection total of 1470 lip print impressions.

3.4 Mark-up

The 300 lifts of Phase I were scanned into AFIX Tracker (AFIX Technologies Inc., 2006, Version 5.0.0.77) (13). A database was created containing all 300 images entitled, “PHASE I”. Scanning was performed with an Epson scanner (Epson Perfection, 4490

Photo, Version 3.04A) in professional mode at 8-bit grayscale and 1200dpi resolution. The photographs were studied to determine minutiae or unique identifying characteristics if they existed. Certain minutiae were defined as: bifurcations, curvatures, diamonds, dots, ending ridges, grids, middle horizontals, open-ended verticals, single horizontals and triangles. Frequencies were determined by utilizing Excel (Microsoft Office Excel, 2003, 11.8316.8221), resulting in 219 rows of data (See *Chapter IV* for frequencies). Analysis was performed for the following factors: upper lip, lower lip, both lips, and a distinction between males and females with respect to the above defined minutiae. Based on the determined frequencies, and the author's experience using AFIX Tracker for fingerprints, rules of mark-up were established. The rules are referred to as the Standard Operating Manual (SOM) for Lip Print Image Compare (LIC) (Appendix D: Table D.1).

SOM for LIC was tested with partial data from Phase I. According to LIC, the four main, potentially useful minutiae Types are the following: bifurcations, triangles, diamonds and middle horizontals. What specifically defines each Type is explained in the SOM (Appendix D: Table D.1). 10 individuals were selected for each Type and marked-up accordingly. This was performed randomly, but if the individual did not provide 3 quality impressions illustrating the specific minutiae Type being sought, then a different random individual was chosen instead (See *Chapter V* for more discussion). Consequently, 10 individuals with 3 impressions each for 4 different Types of minutiae results in the analysis of $(10 \times 3 \times 4)$ 40 individuals and 120 lip print impressions. Once all 120 impressions were marked-up with its chosen minutiae Type, the search wizard function of AFIX Tracker was utilized for each impression to be searched against all latents in the entire AFIX Tracker system, including fingerprints from past work on

AFIX. The stereo image comparison of the first candidate match, along with the entire candidate list was printed for each search (Fig. 3).

FIG. 3—AFIX Report of Two Latent Lip Impressions (28).

The candidate list provided the following columns of information: Description, ID Number and Match Score. Description gave reference to “PHASE I” if it was found within the author’s database or a coded number if it referred to a specific fingerprint found elsewhere. ID Number gave reference to the row in which the latent fell within the database. Match Score is the generated score of the likelihood that the search and the prints were produced by the same finger based on AFIX Tracker’s algorithmic capabilities (13).

On the printed candidate list, the author wrote down the number of total minutiae marked up (# plotted minutiae) in the latent being searched. Afterward, the author opened up each candidate comparison to document beside each candidate how many

minutiae were actually matched (# matched minutiae) to the latent being searched. Only the top 25 candidates in the list were taken into consideration. Then, the “true matches (T+)” were highlighted within the candidate list (ideally, there should be two T+ matches in the list). A Microsoft Excel spreadsheet was created with the following headings: Individual, Latent, # Plotted Minutiae, # Matched Minutiae, Match/Non-Match, Match Score, and Type of Minutiae, resulting in 2908 rows of data in Excel.

In Excel, the first worksheet contained all combined data. Data was extracted and copied into separate worksheets for each Type of minutiae, resulting in 4 additional worksheets. Taking one Type at a time, two pivot tables were created. The first pivot table utilized the “Count” function with the column data: # Matched Minutiae and Match/Non-Match. The table was copied and pasted into a different location, keeping values and number formatting only. From this copied table, future calculations were made and filled the following columns: # Matched Minutiae, True Positive (TP), True Negative (TN), False Positive (FP), False Negative (FN), True Positive Rate (TPR), False Positive Rate (FPR), True Negative Rate (TNR), False Negative Rate (FNR), Area Under Curve (AUC), Sensitivity, Specificity, Selectivity, Positive Likelihood Ratio (LR^+), and Negative Likelihood Ratio (LR^-). Calculations were performed by using the subsequent formulas (Table 9), which were entered in the first cell below the column headings, unless otherwise stated, and copied down to all necessary cells below.

TABLE 9—*Model Component Formulas Used for AFIX Tracker Interpretation.*

TP:	$=($Total$Matches)-SUM($First$Match:FirstMatch)$
TN:	Zero is entered into the 1 st cell; 2 nd cell: $=(FirstNonMatch+FirstCellAbove)$
FP:	$=(Total$NonMatches-AdjacentTNValue)$
FN:	Zero is entered into the 1 st cell; 2 nd cell: $=(FirstMatch+FirstCellAbove)$
TPR:	$=TP/(TP+FN)$ =SENSITIVITY
FPR:	$=FP/(FP+TN)$
TNR:	$=TN/(TN+FP)$
FNR:	$=FN/(FN+TP)$
AUC:	1 st cell is left blank; 2 nd cell: $=AVERAGE(TPR1^{st}cell:TPR2^{nd}cell)*(FPR1^{st}cell:FPR2^{nd}cell)$
SENSITIVITY:	$=TP/(TP+FN)$ =TPR
SPECIFICITY:	$=TN/(TN+FP)$
SELECTIVITY:	$=TP/(TP+FP)$
LR⁺:	$SENSITIVITY/(1-SPECIFICITY)$
LR⁻:	$(1-SENSITIVITY)/SPECIFICITY$

The second pivot table utilized the “Count” function with the column data: Match Scores and Match/Non-Match. The table was copied and pasted into a different location, keeping values and number formatting only. From this copied table, future calculations were made and filled a second set of columns with the same headings noted previously using the same formulas (Table 9). Acquired numbers were compared and any trends

were illustrated via figures and tables including Receiver Operating Characteristic (ROC) curve analysis (See *Chapter IV* for results).

3.5 Internal Review Board

This proposed study was approved by the West Virginia University Internal Review Board (IRB) on August 18, 2009 with protocol number H-21819. A consent and information form resulted (Table E1) providing an agreement between investigator and volunteer.

CHAPTER IV: Results

4.1 Survey

This study was guided by members of the Chesapeake Bay Division of the International Association for Identification (CBD-IAI). A survey of 11 questions (Appendix A: Table A.1) was sent to 63 members resulting in a total of 31 responding agencies, 28 (~ 45%) of which providing useful feedback towards the survey. The following responses were gathered to determine an appropriate direction for research:

1. How common are lip prints in your agency? If possible, provide some numbers (even estimations). Example: Number of cases per year or over a longer period of time.

The most common response was, “We have never had a lip print case” or “We do not encounter or use lip prints”, which held true for approximately 64% of the 44.4% of agencies that responded. The remaining 36% admitted to having seen lip prints in their past casework. Of those 36%, 60% claimed to have dealt with lip prints only once. Responses included, “One time”, “Very uncommon. Once in 18 years” and “One was developed but no additional analysis was requested”. The remaining 40% claimed to have dealt with lip prints on more than one occasion. Responses included, “Received a handful of lip print cases over the past 20 years”, “Never had a case where we compared lip prints. However, we have seen or collected them at crime scenes”, and “Several each year”.

- 2. What is the ratio between the analysis requests on lip prints and fingerprints? If possible, provide some numbers (even estimations). Example: 1 against 100.**

Unanimously, lip print impressions were agreed upon as an uncommon, rare type of evidence in casework. At this time, a ratio cannot be specifically determined.

However, it is known that the ratio would vary amongst agencies.

- 3. When found, in what types of cases were lip prints recovered? [i.e. Homicide, B&E]**

Based on the responses, lip prints were recovered in the following types of cases:

property, threat, vehicle, homicide, “peeping tom”, robbery and breaking and entering, with the last three being the most common.

- 4. When found, what type of support was involved? [i.e. paper, glass]**

Of the 36% of agencies that reported to have acknowledged lip prints in casework, 100% said the lip prints were found on glass, which included windows, doors and drinking glasses. On two different occasions, paper cigarettes were mentioned. In addition, lip prints were once found on metal and duct tape.

- 5. When found, were cosmetics involved?**

a. If yes, what type?

b. If yes, did this alter your method of collection? In what way?

This time, the response was not overwhelming. The most common response was, “No”. However, a couple agencies said, “Mostly with lipstick” and “Sometimes with lipstick”. Consideration should be given to the fact that the agencies responding with, “No” are those that only encountered lip prints one time, while the agencies that said, “Mostly or sometimes with lipstick”, were those that have encountered lip print

impressions on more than one occasion. The method of collection was not necessarily altered, but lipstick *could* indicate a possible female donor.

6. When found, was there an appearance of overlapping?
a. If yes, is this a common occurrence?

Of the 36% of agencies that reported to have acknowledged lip prints in casework, overlapping was never reported. Overlapping impressions does not seem to be a major hindrance, unlike fingerprint impressions.

7. When found, what is your method of collection?

One analyst said, “I collected lip print standards using both the substrate involved as well as lipstick and white paper, taking numerous samples from the subjects”.

Overall, there was a consensus similar to that of fingerprints. First, the impression should be dusted with black powder. Secondly, the image should be photographed before attempting to lift or swab for DNA. Magnetic powder is preferred over regular black powder due to the possibility of leaving streak marks or smears, which could lead to making false interpretations.

8. What is your method of processing and analyzing?

The most common response was, “No analysis took place”. On the other hand, two analysts exclusively said, “I would use ACE Methodology”. In addition, it was mentioned that attention should be given to the medium in determining its porous or nonporous nature. Chemical processing would differ accordingly, similarly to fingerprint development. Moreover, one analyst said, “DNA would be top priority in the analysis. If no DNA resulted and a suspect is known, might ask the lab to analyze

it, comparing it to a known that was given by consent, but we usually use it as a tool for interviewing, yielding confessions”.

9. Did you ever feel lip prints could have been critical to a case?

Mixed reviews were obtained. Some responses included, “No”, and “Not critical, numerous fingerprints were developed with several being identified to a subject”. Yet, other responses included, “YES”, “Thought about it”, and “I was sure that the lip impression could have been useful, but it was an examination for which I was not trained to perform”.

10. Do you feel that lip print identification could be useful if standards were established?

A common agreement was found in that more research is needed. One analyst said, “I believe that lip prints are a positive means of identification. Lip print evidence is another form of pattern evidence. There is always the need for further research, especially about an area, such as lip prints that are rare as evidence”. Another comment was, “Absolutely. I’m confident that lip prints and any other parts of the body, has individualizing value. But the research must be conducted and evidence of uniqueness fully established before it could pass Daubert standards”. Simple replies were, “YES”, “Perhaps” and “I think it has possibilities”. On the other hand, one analyst said, “No, DNA would be better with an already established database”.

11. Do you only focus on patent lip prints or do you consider a search of latent lip prints?

Overall, an agreement was made that both latent and patent lip prints should be searched for at a scene. One analyst said, “I have dealt with both patent and latent lip

prints”. Specifically, another analyst said, “The lip print that I developed in a robbery was a latent print. I do not process a scene with the specific intention of developing lip prints, even on drinking glasses. However, if a patent lip print was observed, it would be appropriately documented and collected”.

The results of the survey were presented at the spring 2009 CBD-IAI conference in an attempt to generate more discussion and interest for this particular study and for lip print identification, in general. The abstract (Table F1) and presentation (Fig. F1) can be found in *Appendix F*. Following the presentation, three main suggestions were given from the FBI. First, Meagher suggested a collection that is more practical to casework by developing latents on a variety of items in a random fashion. Second, Reznicek proposed family studies. Finally, another analyst suggested further study into the physiological aspects of lips (Discussion can be found in *Chapter V*).

4.2 LIC Frequencies

The “PHASE I” database containing 300 scanned lifts (100 individuals, 3 impressions each) from Phase I was studied. Upon review, the following minutiae were recognized and listed in Excel for statistical frequency analysis: bifurcations (up, down, diagonal), diamonds/triangles, dots, grids, middle horizontals, single horizontals (“singles”), and open-ended verticals. Definitions for what each minutiae Type represents can be found in *Chapter V* and Table D1. Irregular patterns such as curvature was found in individual 13 (Fig. 4) and branching was found in individual 47 (Fig. 5).

FIG. 4—*Curvature Found in Individual 13.*

FIG. 5—*Branching Found in Individual 47.*

As a result, the following classification system was devised (Table 10):

TABLE 10—*Edmiston's Initial Lip Print Classification.*

CLASSIFICATION	GROOVE TYPE
Type I	Bifurcations
Type II	Diamonds
Type III	Dots
Type IV	Grids
Type V	Irregulars (Curvature/Branching)
Type VI	Middle Horizontals
Type VII	Open-Ended Verticals
Type VIII	Singles
Type IX	Triangles

Statistical analysis was performed for the following factors: upper lip, lower lip, both lips, and a distinction between males and females with respect to the above defined minutiae.

Consequently, the following minutiae were found with a frequency of 100% for all of the factors defined above: open-ended verticals, bifurcations, dots, and diamonds/triangles. Middle horizontals are a specific Type of minutiae for the upper lip, which also had a frequency of 100% for both males and females. When combining grids and single horizontals (“singles”), thus considering general horizontal minutiae, the frequency was 100% for all factors studied. In addition, separating bifurcations into up, down, and diagonal provided no breakthroughs for discrimination. Therefore, no distinction between males and females could be made based on the chosen minutiae. Furthermore, no distinction between upper lips and lower lips could be made. However some individuals provided more “intricate” lip prints than others (See *Chapter V* for discussion).

Based on the determined frequencies, although not discriminatory, rules of mark-up had to be defined (Table D1). The rules were established based on the authors experience with AFIX Tracker for analyzing fingerprints resulting in the revised lip print classification system for AFIX Tracker (Table 11):

TABLE 11—*Edmiston’s Revised Lip Print Classification for AFIX Tracker.*

CLASSIFICATION	GROOVE TYPE
Type I	Bifurcations
Type II	Diamonds
Type III	Middle Horizontals
Type IV	Triangles

4.3 AFIX Tracker Reliability

SOM for LIC was tested with partial data from Phase I. According to LIC, the four main, potentially useful minutiae Types are the following: bifurcations, triangles, diamonds and middle horizontals. 10 individuals with 3 impressions each for 4 different Types of minutiae results in the analysis of (10 x 3 x 4) 40 individuals and 120 lip print impressions. The obtained data was manipulated in Excel via the formulas in Table 9. An example of a pivot table and calculated figures for diamonds with respect to “# Matched Minutiae and Match/Non-Match” can be found in *Appendix G*. Starting with diamonds, the following figures of line and XY scatter charts are in no particular order:

FIG. 6—*Diamonds: Comparison of Model Components with Respect to the Number of Matched Minutiae.*

In Figure 6, True Negatives (TN) and False Positives (FP) appear inversely proportionate (common trend to all four Types studied) with an overlapping tendency at 4.5 minutiae. For instance, FP decreases from 3 to 9 minutiae, ending at zero and TN increases from 3 to 9 minutiae, ending at one. Likewise, True Positives (TP) and False Negatives (FN) are inversely proportionate (common trend to all four Types studied) with an overlapping tendency at 5 minutiae. False Positives [Type I Error] start to fall to zero at 4 minutiae. False Negatives [Type II Error] start to rise above zero at 4 minutiae. Other approximate intersections of note include TP and TN at 3 minutiae and FN and FP at 7.5 minutiae.

FIG. 7—*Diamonds: Comparison of Type I and II Errors with Respect to the Number of Matched Minutiae.*

In Figure 7, Type I and II error rates are compared proportionately. The False Positive Rate (FPR) and False Negative Rate (FNR) are inversely proportionate with FPR decreasing with the number of matched minutiae as FNR increases (common trend to all four Types studied). Intersection of the two error rates occurs at approximately 5 minutiae. This intersection represents the equal error rate.

FIG. 8—Diamonds: Evaluation of LR^+ and LR^- with Respect to the Number of Matched Minutiae.

In Figure 8, the $\text{Log}(LR^+)$ and $\text{Log}(LR^-)$ are evaluated. The solid line represents $LR^+ = LR^-$. The number of matched minutiae are plotted with less than 5 minutiae falling below the line and greater than 4 minutiae rising above the line.

FIG. 9—Diamonds: Comparison of Specificity, Selectivity, and Sensitivity with Respect to the Number of Matched Minutiae.

Sensitivity and Specificity have an inversely proportionate tendency (common trend to all four Types studied). Sensitivity can also be referred to as the True Positive Rate (TPR). Intersection occurs at 4.5 minutiae with Specificity reaching one at 9 minutiae and Sensitivity reaching zero at 12 minutiae. Selectivity tends to increase slightly starting at 5 minutiae, but a change in trend occurs with a decrease between 9 and 10 minutiae. Selectivity never reaches a maximum height. Other approximate intersections include Specificity and Selectivity at 3 minutiae and Sensitivity and Selectivity at 7.5 minutiae.

FIG. 10—*Diamonds: Receiver Operating Characteristics (ROC) Curve Comparing True Positive Rate (TPR) and False Positive Rate (FPR) for Matched Minutiae.*

Figure 10 illustrates the calculated Area Under the Curve (AUC) for the relationship of FPR (x-axis) and TPR (y-axis), given the number of matched minutiae. The AUC summation was calculated to be 0.604. A smoothed line was added to emphasize the area under the curve that falls between 0 and 1.

In the following figure, (Fig. 11), the model components were compared given the match scores accumulated for diamond Type minutiae. The results are similar to the prior component comparison with respect to number of matched minutiae (Fig. 6). TN and FP appear inversely proportionate (common trend to all four Types studied) overlapping at match score 22788. FP persistently decreases until reaching zero at approximate match score 268430. TN persistently increases until reaching one at the same approximate match score. Similarly, TP and FN are inversely proportionate (common trend to all four Types studied) overlapping at match score 30888. The range of match scores depicted is from 168 to 268430. False Positives [Type I Error] start to fall drastically to zero immediately. False Negatives [Type II Error] start to rise slightly and gradually. Other approximate intersections of note include TP and TN at match score 5532 and FN and FP at match score 83850.

FIG. 11—Diamonds: Comparison of Model Components with Respect to the Match Scores.

In Figure 12, the results are similar to the prior comparison of Selectivity, Specificity and Sensitivity with respect to number of minutiae matched (Fig. 7). Sensitivity and Specificity have an inversely proportionate tendency, but this time, Specificity is more persistent (common trend to all four Types studied). Intersection occurs at match score 26028. Specificity increases until reaching one at approximate match score 268430. Sensitivity decreases until reaching zero at the same approximate match score. Selectivity tends to increase slightly starting at match score 18982. At match score 151022, Selectivity tends to increase more drastically, but no maximum height is reached, instead, a change in trend occurs at match score 190002 with one point landing on zero at score 268430. Other approximate intersections include Specificity and Selectivity at match score 5092 and Sensitivity and Selectivity at 88714 minutiae.

FIG. 12—*Diamonds*: Comparison of Specificity, Selectivity, and Sensitivity with Respect to the Match Scores.

The following figure, (Fig. 13), illustrates the calculated AUC for the relationship of FPR (x-axis) and TPR (y-axis), given the accumulated match scores. The AUC summation was calculated to be 0.615. A smoothed line was added to emphasize the area under the curve that falls between 0 and 1.

FIG. 13—Diamonds: Receiver Operating Characteristics (ROC) Curve Comparing True Positive Rate (TPR) and False Positive Rate (FPR) for Match Scores.

Continuing with middle horizontals, in Figure 14, TN and FP have an overlapping tendency at 5.25 minutiae. FP decreases from 3 to 12 minutiae, ending at zero and TN increases from 3 to 12 minutiae, ending at one. TP and FN overlap at 6.5 minutiae. False Positives [Type I Error] start to fall to zero at 3 minutiae. False Negatives [Type II Error] start to rise above zero at 3 minutiae. Other approximate intersections include TP and TN at 3.25 minutiae and FN and FP at 9.5 minutiae.

FIG. 14—*Middle Horizontals: Comparison of Model Components with Respect to the Number of Matched Minutiae.*

FIG. 15—*Middle Horizontals: Comparison of Type I and II Errors with Respect to the Number of Matched Minutiae.*

In Figure 15, Type I and II error rates are compared proportionately. The False Positive Rate (FPR) and False Negative Rate (FNR) are inversely proportionate with FPR decreasing with the number of matched minutiae as FNR increases. Intersection of the two error rates occurs at approximately 6 minutiae.

FIG. 16—*Middle Horizontals: Evaluation of LR^+ and LR^- with Respect to the Number of Matched Minutiae.*

In Figure 16, the $\text{Log}(LR^+)$ and $\text{Log}(LR^-)$ are evaluated. The solid line represents $LR^+ = LR^-$, which is where 6 matched minutiae is plotted. The remaining number of matched minutiae are plotted elsewhere with less than 6 minutiae falling below the line and greater than 6 minutiae rising above the line.

Sensitivity and Specificity intersection occurs at 6 minutiae with Specificity reaching one at 12 minutiae and Sensitivity reaching zero at 15 minutiae. Selectivity tends to increase slightly starting at 5 minutiae. A more drastic increase starts at 10 minutiae resulting in a maximum height of one at 14 minutiae. Other approximate intersections of note include Specificity and Selectivity at 3.25 minutiae and Sensitivity and Selectivity at 9.5 minutiae.

FIG. 17—Middle Horizontals: Comparison of Specificity, Selectivity, and Sensitivity with Respect to the Number of Matched Minutiae.

Figure 18 illustrates the calculated AUC for the relationship of FPR (x-axis) and TPR (y-axis), given the number of matched minutiae. The AUC summation was calculated to be 0.673. A smoothed line was added to emphasize the area under the curve that falls between 0 and 1.

FIG. 18—*Middle Horizontals: Receiver Operating Characteristics (ROC) Curve Comparing True Positive Rate (TPR) and False Positive Rate (FPR) for Matched Minutiae.*

In the following figure, (Fig. 19), the model components were compared given the match scores accumulated for middle horizontal Type minutiae. TN and FP overlap at match score 17469. FP persistently decreases until reaching zero at approximate match score 79633. TN persistently increases until reaching one at the same approximate match score. TP and FN overlap at match score 36390. The range of match scores depicted is from 387 to 672765. False Positives [Type I Error] start to fall drastically to zero immediately. False Negatives [Type II Error] rise slightly and gradually. Other approximate intersections of note include TP and TN at match score 2925 and FN and FP at match score 55089.

FIG. 19—Middle Horizontals: Comparison of Model Components with Respect to the Match Scores.

In Figure 20, Sensitivity and Specificity intersection occurs at match score 24408. Specificity increases until reaching one at approximate match score 260676. Sensitivity decreases until reaching zero at the same approximate match score. Selectivity gradually increases until a drastic increase at match score 57435. A decrease occurs starting at match score 154648 for a few points, but Selectivity has one point reaching a maximum at one with match score 260676. Other approximate intersections include Specificity and Selectivity at match score 2484 and Sensitivity and Selectivity at 59159 minutiae.

FIG. 20—*Middle Horizontals: Comparison of Specificity, Selectivity, and Sensitivity with Respect to the Match Scores.*

The following figure, (Fig. 21), illustrates the calculated AUC for the relationship of FPR (x-axis) and TPR (y-axis), given the accumulated match scores. The AUC summation was calculated to be 0.758. A smoothed line was added to emphasize the area under the curve that falls between 0 and 1.

FIG. 21—*Middle Horizontals: Receiver Operating Characteristics (ROC) Curve Comparing True Positive Rate (TPR) and False Positive Rate (FPR) for Match Scores.*

Continuing with triangles, in Figure 18, TN and FP have an overlapping tendency at 4.75 minutiae. FP decreases from 3 to 8 minutiae, ending at zero and TN increases from 3 to 8 minutiae, ending at one. TP and FN have an overlapping tendency at 4 minutiae. False Positives [Type I Error] start to fall to zero at 3 minutiae. False Negatives [Type II Error] start to rise above zero at 4 minutiae. Other approximate intersections include TP and TN at 3.25 minutiae and FN and FP at 6.75 minutiae.

FIG. 22—Triangles: Comparison of Model Components with Respect to the Number of Matched Minutiae.

FIG. 23—*Triangles: Comparison of Type I and II Errors with Respect to the Number of Matched Minutiae.*

In Figure 23, Type I and II error rates are compared proportionately. The False Positive Rate (FPR) and False Negative Rate (FNR) are inversely proportionate with FPR decreasing with the number of matched minutiae as FNR increases. Intersection of the two error rates occurs at approximately 5 minutiae.

FIG. 24—Triangles: Evaluation of LR^+ and LR^- with Respect to the Number of Matched Minutiae.

In Figure 24, the $\text{Log}(LR^+)$ and $\text{Log}(LR^-)$ are evaluated. The solid line represents $LR^+ = LR^-$. The number of matched minutiae are plotted with less than 5 minutiae falling below the line and greater than 6 minutiae rising above the line.

For triangles, Sensitivity and Specificity intersection occurs at 4.5 minutiae with Specificity reaching one at 8 minutiae and Sensitivity reaching zero at 10 minutiae. Selectivity tends to increase slightly starting at 5 minutiae. A drastic increase occurs from 7 to 8 minutiae followed by a severe decrease from 8 to 9 minutiae. No maximum height of one occurs. Other approximate intersections of note include Specificity and Selectivity at 3.25 minutiae and Sensitivity and Selectivity at 6.75 minutiae.

FIG. 25—*Triangles: Comparison of Specificity, Selectivity, and Sensitivity with Respect to the Number of Matched Minutiae.*

The following figure, (Fig. 26), illustrates the calculated AUC for the relationship of FPR (x-axis) and TPR (y-axis), given the number of matched minutiae. The AUC summation was calculated to be 0.475. A smoothed line was added to emphasize the area under the curve that falls between 0 and 1.

FIG. 26—Triangles: Receiver Operating Characteristics (ROC) Curve Comparing True Positive Rate (TPR) and False Positive Rate (FPR) for Matched Minutiae.

In the next figure, (Fig. 27), the model components were compared given the match scores accumulated for triangle Type minutiae. TN and FP overlap at match score 17795. FP persistently decreases until reaching zero at approximate match score 174248. TN persistently increases until reaching one at the same approximate match score. TP and FN overlap at match score 20410. The range of match scores depicted is from 82 to 174248. False Positives [Type I Error] start to fall drastically to zero immediately. False Negatives [Type II Error] rise slightly and gradually. Other approximate intersections of note include TP and TN at match score 864 and FN and FP at match score 56506.

FIG. 27—Triangles: Comparison of Model Components with Respect to the Match Scores.

In Figure 28, Sensitivity and Specificity intersection occurs at match score 18095. Specificity increases until reaching one at approximate match score 174248. Sensitivity decreases until reaching zero at the same approximate match score. Selectivity gradually increases until a drastic increase at match score 56901. A decrease occurs starting at match score 146469 for a few points, but Selectivity has one point reaching a maximum at one with match score 174248. Other approximate intersections include Specificity and Selectivity at match score 846 and Sensitivity and Selectivity at 54236 minutiae.

FIG. 28—*Triangles: Comparison of Specificity, Selectivity, and Sensitivity with Respect to the Match Scores.*

The following figure, (Fig. 29), illustrates the calculated AUC for the relationship of FPR (x-axis) and TPR (y-axis), given the accumulated match scores. The AUC summation was calculated to be 0.547. A smoothed line was added to emphasize the area under the curve that falls between 0 and 1.

FIG. 29—Triangles: Receiver Operating Characteristics (ROC) Curve Comparing True Positive Rate (TPR) and False Positive Rate (FPR) for Match Scores.

Finally with bifurcations, in Figure 30, TN and FP have an overlapping tendency at 4.25 minutiae. FP decreases from 3 to 8 minutiae, ending at zero and TN increases from 3 to 8 minutiae, ending at one. TP and FN have an overlapping tendency at 5 minutiae. False Positives [Type I Error] start to fall to zero at 3 minutiae. False Negatives [Type II Error] start to rise above zero at 4 minutiae. Other approximate intersections include TP and TN at 3 minutiae and FN and FP at 6.75 minutiae.

FIG. 30—Bifurcations: Comparison of Model Components with Respect to the Number of Matched Minutiae.

FIG. 31—*Bifurcations: Comparison of Type I and II Errors with Respect to the Number of Matched Minutiae.*

In Figure 31, Type I and II error rates are compared proportionately. The False Positive Rate (FPR) and False Negative Rate (FNR) are inversely proportionate with FPR decreasing with the number of matched minutiae as FNR increases. Intersection of the two error rates occurs at approximately 5 minutiae.

FIG. 32—Bifurcations: Evaluation of LR^+ and LR^- with Respect to the Number of Matched Minutiae.

In Figure 32, the $\text{Log}(LR^+)$ and $\text{Log}(LR^-)$ are evaluated. The solid line represents $LR^+ = LR^-$. The number of matched minutiae are plotted with less than 7 minutiae falling below the line and greater than 6 minutiae rising above the line.

For bifurcations, Sensitivity and Specificity intersection occurs at 4.5 minutiae with Specificity reaching one at 8 minutiae and Sensitivity reaching zero at 15 minutiae. Selectivity tends to increase slightly starting at 4 minutiae and continues more drastically until reaching the maximum height of one at 12 minutiae. Other approximate intersections of note include Specificity and Selectivity at 3 minutiae and Sensitivity and Selectivity at 6.75 minutiae.

FIG. 33—Bifurcations: Comparison of Specificity, Selectivity, and Sensitivity with Respect to the Number of Matched Minutiae.

The following figure, (Fig. 34), illustrates the calculated AUC for the relationship of FPR (x-axis) and TPR (y-axis), given the number of matched minutiae. The AUC summation was calculated to be 0.735. A smoothed line was added to emphasize the area under the curve that falls between 0 and 1.

FIG. 34—*Bifurcations: Receiver Operating Characteristics (ROC) Curve Comparing True Positive Rate (TPR) and False Positive Rate (FPR) for Matched Minutiae.*

In the next figure, (Fig. 35), the model components were compared given the match scores accumulated for bifurcation Type minutiae. TN and FP overlap at match score 9306. FP persistently decreases until reaching zero at approximate match score 141945. TN persistently increases until reaching one at the same approximate match score. TP and FN overlap at match score 17648. The range of match scores depicted is from 72 to 141945. False Positives [Type I Error] start to fall drastically to zero immediately. False Negatives [Type II Error] rise slightly and gradually. Other approximate intersections of note include TP and TN at match score 666 and FN and FP at match score 25542.

FIG. 35—Bifurcations: Comparison of Model Components with Respect to the Match Scores.

In Figure 36, Sensitivity and Specificity intersection occurs at match score 11375. Specificity increases until reaching one at approximate match score 141945. Sensitivity decreases until reaching zero at the same approximate match score. Selectivity gradually increases until a drastic increase at match score 25542. A decrease occurs starting at match score 95424 for a few points, but Selectivity has one point reaching a maximum at one with match score 141945. Other approximate intersections include Specificity and Selectivity at match score 657 and Sensitivity and Selectivity at 29349 minutiae.

FIG. 36—Bifurcations: Comparison of Specificity, Selectivity, and Sensitivity with Respect to the Match Scores.

The following figure, (Fig. 37), illustrates the calculated AUC for the relationship of FPR (x-axis) and TPR (y-axis), given the accumulated match scores. The AUC summation was calculated to be 0.693. A smoothed line was added to emphasize the area under the curve that falls between 0 and 1.

FIG. 37—*Bifurcations: Receiver Operating Characteristics (ROC) Curve Comparing True Positive Rate (TPR) and False Positive Rate (FPR) for Match Scores.*

The following two tables and figures provide summaries to prior information. The first table, (Table 12), provides a comparison of AUC summations in descending order for all four Types of minutiae when considering the number of matched minutiae, previously displayed as ROC curves.

TABLE 12—*Comparison of AUC Summations for Four Types of Minutiae (Matched Minutiae)*

AUC Summation Comparison (Matched Minutiae)	
Type of "Minutiae"	AUC Score
Bifurcations	0.735
Middle Horizontals	0.673
Diamonds	0.604
Triangles	0.475

The first figure, (Fig. 38), provides a summary of the above table (Table 12).

FIG. 38—*All Four Types: Receiver Operating Characteristics (ROC) Curve Comparing True Positive Rate (TPR) and False Positive Rate (FPR) for Matched Minutiae.*

The second table, (Table 13), provides a comparison of AUC summations in descending order for all four Types of minutiae when considering the accumulated match scores, previously displayed as ROC curves.

TABLE 13—*Comparison of AUC Summations for Four Types of Minutiae (Match Scores).*

AUC Summation Comparison (Match Scores)	
Type of "Minutiae"	AUC Score
Middle Horizontals	0.758
Bifurcations	0.693
Diamonds	0.615
Triangles	0.547

The second figure, (Fig. 39), provides a summary of the above table (Table 13).

FIG. 39—*All Four Types: Receiver Operating Characteristics (ROC) Curve Comparing True Positive Rate (TPR) and False Positive Rate (FPR) for Match Scores.*

The next figure, (Fig. 40), approximates the Likelihood Ratios (LR) based on the ROC curve established for the number of matched minutiae (35). The bifurcation Type is represented to illustrate the best AUC result of approximately 0.735 (blue curve). The black solid line represents a coin toss discrimination, which is where Sensitivity = (1 - Specificity). The gray solid line represents a constant positive likelihood ratio of 81, whilst the dotted gray line represents a constant negative likelihood ratio of 0.88. These lines cut off at 9 minutiae with an odds ratio of approximately 93, the best odds ratio detected. The black dotted line divides the discriminatory regions into two quadrants. Above the thick solid and dashed lines $|\text{Log}(\text{LR}^-)| > |\text{Log}(\text{LR}^+)|$, which is where the number of matched minutiae below 5 are plotted. Between the thick solid and dashed lines $|\text{Log}(\text{LR}^+)| > |\text{Log}(\text{LR}^-)|$, which is where the number of matched minutiae above 4 are plotted.

FIG. 40—Bifurcations: Approximating LR based on Receiver Operating Characteristics (ROC) Curve for Matched Minutiae.

The table below, (Table 14), summarizes all calculated odds ratios for bifurcation Type minutiae with respect the number of matched minutiae. The best result occurred with 9 minutiae, which was displayed in the previous figure (Fig. 40).

TABLE 14—*Summary of Calculated Odds Ratios for Bifurcations (Matched Minutiae).*

BIFURCATIONS	
# Matched Minutiae	Odds Ratios: (LR+/LR-)
0	-
2	-
3	0.782
4	2.85
5	6.29
6	13.1
7	19.2
8	77.1
9	92.7
11	76.4
12	-
13	-
15	-

Two tables, (Tables H1 and H2), provide summary information for the points of intersection with respect to both matched minutiae and match scores, which can be found in *Appendix H*. Table H3 was also created to summarize “Max Out” points for a comparison of when certain model components reached either zero or one (See *Appendix H*). .

The following tables provide other summary information including the number of matched minutiae where non-matches ceased to exist, the number of matched minutiae where matches started to exist, and the overall largest number of matched minutiae for each Type in descending order.

TABLE 15—*Summary of Four Types Considering Disappearance of Non-Matches.*

Non-Matches Stopped at: (# of Matched Minutiae)	
Middle Horizontals	14
Bifurcations	12
Diamonds	12
Triangles	10

TABLE 16—*Summary of Four Types Considering Appearance of Matches.*

Matches Did Not Occur Until: (# of Matched Minutiae)	
Diamonds	3
Triangles	3
Bifurcations	2
Middle Horizontals	2

TABLE 17—*Summary of Four Types Considering Largest Number of Matched Minutiae.*

Largest: (# of Matched Minutiae)	
Bifurcations	15
Middle Horizontals	15
Diamonds	12
Triangles	10

In addition to matched minutiae and match scores, the placement of matches within the top 25 candidates was studied. Ideally, two matches should be within the top 25 candidates, the frequencies of this situation are summarized in the following table for all four Types of minutiae in descending order (Table 18). The summaries of the occurrence

of one match and zero matches within the top 25 for all four Types of minutiae in descending order are also summarized in Tables 19 and 20 below.

TABLE 18—*Summary of Four Types Considering Two Matches within Top 25 Candidates.*

Two Matches within Top 25 Candidates (% Frequency)	
Diamonds	76.7
Middle Horizontals	76.7
Bifurcations	46.7
Triangles	36.7

TABLE 19—*Summary of Four Types Considering One Match within Top 25 Candidates.*

One Match within Top 25 Candidates (% Frequency)	
Triangles	43.3
Bifurcations	33.3
Diamonds	20.0
Middle Horizontals	20.0

TABLE 20—*Summary of Four Types Considering Zero Matches within Top 25 Candidates.*

Zero Matches within Top 25 Candidates (% Frequency)	
Bifurcations	20.0
Triangles	20.0
Diamonds	03.3
Middle Horizontals	03.3

CHAPTER V: Discussion

5.1 Introduction

Cheiloscopy refers to the study of lip prints (1). Bindal stated, “Cheiloscopic techniques have an equal value in relation to other types of forensic evidences for personal identification (21). This statement and others such as the following are too bold at the current stage of lip print research. Ryu said, “The individual furrow patterns of the lips are more apparent than fine wrinkles; thus, it is a reliable identifying marking like fingerprints (30). Lip prints have been proposed as a type of impression evidence with similar issues as fingerprints, but with greater scrutiny due to a lack of history in using this type of impression as evidence. Although lip prints have been studied for over a century, they are not commonly recovered at crime scenes. In fact, lip print identification has been given little acknowledgement with limited research being conducted. More research must be performed if lip print identification will ever have the chance of achieving *Frye* or *Daubert* standards. Coward commented,

Past papers have limited themselves totally to the line patterns of the vermillion region. Many other features that appear on a lip print may be of relevance to individualization and should be explored. Techniques need to be developed to allow the recording of lip prints from suspects to create a database and to collect evidential prints for comparison with those on file (24).

Castello agreed with the following statement,

The use of lip prints is more restrictive because databases of lip prints do not exist. However, this type of evidence can be useful for identification if it is possible to compare the latent lip print with the lip prints of a suspect (27).

In this study, a database was constructed by using AFIX Tracker. In utilizing this minutiae-based system, there was an underlying assumption that minutiae mark-up via

classification was a good approach towards lip print individualization. However, not all examiners would agree. The author recently participated in a workshop held by John Vanderkolk on lip, elbow, and other skin impressions (36). Vanderkolk never once spoke about the importance of classification with specifically defined minutiae, instead, he would only say, “comparative measurements, details, and repeatable features” (36, 37). However, he did believe in uniqueness with the acknowledgment of textures and wrinkles. He said,

As skin is part of nature, all parts of skin are unique. The embryological and fetal development and then later regeneration of skin produce surfaces that bear the unique natural patterns of textures, creases, wrinkles, ridges and imperfections (37).

Yet, most of the authors included in this study’s literature review argue with Vanderkolk, including pioneer Tsuchihashi:

In general, because the lip print is on the ruddy part, or the zone of transition, of the lips, which are extremely mobile, it may differ in appearance according to pressure, direction and method used in taking the lip print, frequently becomes mistaken for that of another person. Basically, however, Type I never appears like Type II. Therefore, the classification of the lip print is valuable in reducing the number of items to be compared, and the discernment of identity should be made, as in the case of fingerprints, ultimately by finding characteristic points to establish diagnosis (6).

Contradictory of his prior statements, in a book entitled, “Challenges to Fingerprints”, Vanderkolk stated the following:

With unfamiliar images there is no template. The examiner must use visible, describable characteristics to compare. Examiner must assign specific spatial locations to every feature in the fingerprint (10).

Although the prior statement was guided towards fingerprints, would lip prints also be unfamiliar images without a template? Would the examiner have to use, “visible, describable characteristics to compare”? In referring to fingerprints, surely Vanderkolk

was referring to “minutiae” like any other fingerprint examiner. Why the opposition to specifically define these visible, describable, supposedly unique characteristics for lip prints? If defined, given the acceptance of lip print evidence, would this assist in a common language for court testimony?

This study’s results validated what Coward once said:

Firstly, many lip prints do not consist of areas of purely one Type, commonly several Types were superimposed. Secondly, it was possible for two or more individuals to bear the same pattern of Types but differ in the detailed morphology. This suggests that the classifications may assist in searching through large databases, which as yet do not exist, but are of limited use in distinguishing or identifying individuals. This must be done by a comparison of the fine details (24).

5.2 Literature Review

Most of the recent literature found contained repetitive historical facts about the pioneers of lip print identification followed by a couple paragraphs of their own contribution. In fact, most of the literature found was based off the work of pioneers Suzuki and Tsuchihashi. Moreover, most used lipsticks for their collection of lip prints. The main limitation for all studies was their small sample size. Coward found more limitations:

Suzuki and Tsuchihashi collected data by both photography and/or direct contact prints, which were then traced by hand onto cellophane. This technique ignores the networks of fine detail in favor of the gross lines. The operator’s value judgment, as well as their physical adeptness makes this process extremely operator dependent and poorly reproducible (24).

Lip prints are intricate and more complex than fingerprints, which provides issues with reproducibility and arguments over classification. Most of the literature mentioned

minutiae, or unique identifying characteristics, as “Grooves”. However, Coward used the term, “Notches” and Vanderkolk’s philosophy has already been discussed (1, 24, 36).

First, a closer look at the pioneers in comparison to this study. Recall, the following is the initial classification system devised by the author based on the current study:

TABLE 10—*Edmiston’s Initial Lip Print Classification.*

CLASSIFICATION	GROOVE TYPE
Type I	Bifurcations
Type II	Diamonds
Type III	Dots
Type IV	Grids
Type V	Irregulars (Curvature/Branching)
Type VI	Middle Horizontals
Type VII	Open-Ended Verticals
Type VIII	Singles
Type IX	Triangles

Renaud, Suzuki and Tsuchihashi found, “Complete and Incomplete Vertical” groove Types (1). Similarly, Afchar-Bayat found, “Vertical and straight grooves covering the whole lip; and like the former, but not covering the whole lip” (1). The author found the same characteristics, but defined complete verticals as “Open-Ended Verticals” since the groove stretches the entire length leaving open ends both north and south of the lip and incomplete verticals as “Ending Ridges”, not listed in the above classification but noted in SOM for LIC (*Appendix D*).

Everyone found branching grooves. However, Suzuki and Tsuchihashi simply stated, “Branched”, Renaud separated complete from incomplete branching, and Afchar-Bayat acknowledged straight and angulated branching (1). The author is not sure what incomplete branching refers to, perhaps it could correspond to “Singles” with a frayed

single horizontal coming off of a long vertical. At first glance, the author's classification is more like Afchar-Bayat's, with mention of up, down and diagonal "bifurcations" or branching (19).

Specifically, Afchar-Bayat stated:

Branched grooves were found to divide upwards in the upper lip and downwards in the lower, as reported by Suzuki and Tsuchihashi, but some grooves, the so called II' Type were found to branch the other way around (1, 18).

Again, the author agrees with Afchar-Bayat. Bifurcations were found pointing in all directions in upper and lower lips (Fig. 41).

FIG. 41—*Volunteer 6 Showing Bifurcations in All Directions on Both Lips.*

Furthermore, the author referred to "branching" when finding curving branches resembling "tree roots" in individual 47 (Fig. 42). This could be what Renaud considered branching since he also mentioned "Complete and Incomplete Bifurcated" (1). The other

pioneers never mentioned “bifurcated” (1). Therefore, at second glance, the author’s classification is more like Renaud’s with a distinction between branching and bifurcations (17).

FIG. 42—*Curved Branching Found in Individual 47.*

Previously mentioned, lip prints are intricate and more complex than fingerprints, which provides issues with reproducibility and arguments over classification. The arguments continue as the intricacies of the lip prints are attempted to be defined. All pioneers mention a groove Type as “Reticular”, which is defined by Webster as, “of or like a net; netlike and intricate; entangled” (38). This would fall under the author’s classification of “grid” Type minutiae. Additionally, Afchar-Bayat mentioned “Converging” grooves and Suzuki and Tsuchihashi mentioned not only “Reticular” but also “Intersected” (1). The author is unsure of what defines each to constitute their own category. With this fact and along with neglecting bifurcations as their own Type, and soon to be discussed, a complete negligence of shapes such as triangles and diamonds, should most of the studies really be based on Suzuki and Tsuchihashi’s classification system?

Suzuki and Tsuchihashi never mentioned triangles or diamonds specifically but stated “Irregular” (1). Similarly, Afchar-Bayat Renaud played it safe and said, “Other Grooves”

(1). On the other hand, Renaud purposely singled out ellipses and triangles under “Other Forms” (1). Moreover, Renaud was the only pioneer mentioned to specifically state “Horizontal” as a Type (1). More specifically, the author mentioned “Singles” and “Middle Horizontals”. Singles referred to random, single horizontal lines that were found, but not necessarily within a grid-like or reticular pattern. Typically, they would form other identifying characteristics such as bifurcations or triangles. Upon gaining experience with lip prints, the distinction of singles through the reproducibility of mark-up is challenging. Hence, the author retracts “Singles” as being a separate Type. One exception lies with “Middle Horizontals”. The author feels there could be significance in focusing on the upper lip below the philtrum for the presence of horizontal lines.

Secondly, a closer look at recent studies in comparison to this study. In following the order of the literature review, Saraswathi, Mishra and Ranganathan made the following conclusions based on their observations. First, “No two or more individuals had a similar type of lip print pattern” (20). Second, intersecting patterns were found to be most common both among males and females having frequencies of 39.5% and 36.5%, respectively (20). Third, the least common pattern found was the reticular Type seen in 11.0% males and 13.0% females (20). For this study at this time, the author will not say if all individuals produced different lip prints. In addition, the difference between intersecting and reticular patterns is not defined. Certainly, grid-like and intricate patterns do appear. Most certainly, some individuals produce more intricate patterns than others, but the author tends to believe it is more complicated. The production of said intricate patterns are very much dependant upon the quality and expression of the lip print. Similarly, with their study stating 39.5% and 11.0% for males and 36.5% and

13.0% for females, this study verified there is no real distinction between males or females at this time. Also, 10.25% of all lip prints obtained were thrown out of their study due to poor quality (20). Similarly, 10% of all lips, thus far in Phase I were thrown out of this study for similar reasons. Saraswathi blamed poor quality on male facial hair, but lip prints from this study were thrown out mainly due to pressure. Male facial hair was a hindrance, as seen in the figure below, but enough detail is available for analysis elsewhere (Fig. 43).

FIG. 43—*Slight Hindrance of Male Facial Hair.*

Bindal created a study utilizing the dental formula (21). By examination, lip prints showed combinations of patterns to be present in all quadrants (21). Similarly to Saraswathi in the previous study, Bindal claimed no two lip prints of individuals' matched with each other (21). The most frequent pattern in males studied was the partial length groove (M: 60.5%; F: 66.8%) and the least observed pattern was branching (M:

29.7%; F: 27.0%) (21). Again, it was verified that no real distinction was found between males and females. Moreover, Bindal's observations revealed no change in the lip print patterns with change in time (21). For this study at this time, the author will not say if no changes occurred in lip print patterns with change in time.

Vahanwala, Nayak and Pagare performed a study to ascertain whether lip prints behold potential for the determination of sex of an individual (23). Of note, of the 20 males, 16 were correctly identified as males, 1 incorrectly as a female and 3 were inconclusive (23). The authors reasoned out the mistake by clarifying that trends of both the sexes were prevalent at the same time and variant Types in all quadrants made decision making for the researchers a little difficult (23). Recall, Vahanwala, Nayak and Pagare made their determinations based on the following table derived from Vahanwala-Parekh (Table 8) (23).

TABLE 8—*Vahanwala-Parekh's Results.*

Lip-pattern	Region of occurrence	Predominantly seen in
a. Type I & Type II	1st quadrant [right upper lip]	Female
b. Type II	2nd quadrant [left upper lip]	Male
c. Type III	Never occurs in lower lip	If so then only in Male
d. Varied patterns	In all quadrants	Male
e. Same [alike] patterns	In all quadrants	Female

The key word to the above table is “predominantly”. At this time, the author cannot say if the above table's “a and b” corresponds to the findings of this study. Bullet “c” refers to criss-cross pattern devised by Suzuki. Maybe mistaken, but it is the opinion of the author that the below female produced criss-cross patterns in the lower lip (Fig. 44).

FIG. 44—*Female Producing “Type III” in Lower Lip.*

At this time, the author cannot say if the prior table’s “d and e” corresponds to the findings of this study because quadrants were not used. Yet, in agreement, the prevalence of variant Types in all quadrants does make decision making for researchers, “a little difficult”.

In fact, the next researcher, Coward, considered the classification to be too complicated and confusing (24). Instead, the study was confined to major pattern types (i.e. linear, reticular, and mixed) and fine pattern details (24). The author is unsure of what “fine pattern details” means. It seems to be an approach similar to that of Vanderkolk in which any area persistently perceived has the potential to be identified. Vanderkolk stated,

Ultimately, if a source has perceivable features that are persistent and unique and leaves two sufficient images, it does not matter what the object is. It does not matter what the substrate is as long as the substrate can maintain the pattern. It just does not matter (37).

Coward concluded there is a considerable variation in the lip’s overall shape (24).

Furthermore, it was explained how some of these characteristics may vary over time due to muscle posturing or recording conditions but the overall shape should be recognizable

and help to distinguish one from another (24). Coward observed that most people will leave some print of nose, philtrum, upper and lower lip and possibly chin. Therefore the width and appearance where the philtrum joins the upper lip may also provide identification data (24). Vanderkolk also mentioned this phenomenon with respect to commissures, the angles of the mouth where the upper and lower lips meet (8, 36). At times, the above facial features were recorded. Separate examples follow in Figure 45 and Figure 46. However, the author warns caution against using these features towards individualization. Similar to 3rd level detail of fingerprints, reproducibility is an issue. Clarity must be high with the features being present in both the unknown and the known for a proper comparison.

FIG. 45—*Individual Producing Philtrum, Upper Lip, Lower Lip, and Chin.*

FIG. 46—*Commissures Recorded at the Corners of the Mouth.*

Furthermore, Coward mentioned “8” as being the significant number when counting points of concordance for his study. Why is the number eight significant? Coward also mentioned limiting his study to a subset of the original number of individuals due to an issue of some individuals failing to leave a visible print and/or impossible to determine their pattern type (24). For the determination of sex, Coward observed 90.0% of females to have facial hair. In this study, an exact percentage was not calculated, but facial hair was found on certain females. Therefore, the presence of facial hair for the determination of sex, specifically, is unreliable. One should not assume a male with the presence of facial hair. Similarly, one should not assume female for the presence of lipstick, a mistake once made by the FBI (39).

Again, many of the recent studies utilized lipstick for the retrieval of lip impressions. Crime scene investigators must be aware that popular long-lasting lipsticks can be

formulated to be invisible. Certain studies proved lysochromes (Sudan III, Oil Red O, and Sudan Black) could assist in the development of latent prints (25, 26). In addition, Nile Red was studied and seemed to produce good quality development (27, 28). More research is needed to validate these findings and determine other developers that could also produce high-quality prints.

Unfortunately, lip print evidence has been prematurely placed in the court room. One should be careful in stating the following:

Identification using lip prints was first performed in the 1950s and was the subject of much research in the 1960s and 70s leading to the acceptance of this technique as evidence in the criminal justice system (22).

Further proof lies in the *People vs. Davis* case (32). The direct appeal filed by Davis provided solid arguments including issues relating to the fulfillment of *Frye* standards (32). Lip print testimony resulted, perhaps valid, but lacking support from reliable research. As stated before, the purpose of this study is to provide awareness of lip print identification. The intent is not to stimulate a premature use of lip print identification in actual casework today, but simply to stimulate the research and testing needed for this type of evidence to ever have a chance of becoming accepted. Saraswathi understood this concept:

Although lip prints identification has been utilized in the court in isolated cases, more researches need to be conducted in this field with regards to confirmation of uniqueness, and the collection and interpretation of evidence (20).

5.3 Materials and Methods

This study was guided by members of the Chesapeake Bay Division of the International Association for Identification (CBD-IAI). These active forensic scientists

took the time out of their busy schedules to provide recommendations towards relevant and practical materials and methods for the handling of this type of evidence.

Phase I involved a larger number of volunteers than Phase II with 100 individuals. All 100 individuals provided 3 impressions each, allowing for the analysis of intervariability. Intervariability refers to the variability between different individuals by answering the following question, “Can this individual be discriminated from another individual?” thus approaching uniqueness. 10 volunteers (10.0%) were thrown out of Phase I due to unacceptable quality. It was the opinion of the author that quality was insufficient for purposes of AFIX Tracker, but may still be suitable for comparison by other means. 10 new volunteers were selected as replacements, resulting in a collection total of 300 lip print impressions for Phase I.

Phase II involved a smaller number of volunteers than Phase I with 50 individuals. All 50 individuals provided 6 impressions each 5 different times, allowing for the analysis of intravariability. Intravariability refers to the variability within an individual by answering the following question, “For this individual, is this same characteristic present three months later?” thus approaching persistence. Although attempting to answer questions about uniqueness and persistence, due to the small sample size, limited number of samples, and other limiting factors previously mentioned, the analysis does not contain certainty. Coward elaborates with this statement,

It is clear from the literature that there is a need for further clarification before lip patterns can be of forensic use. There is no credible research on the stability of lip detail over time. Sample sizes have been too small to be credible scientifically or in a court of law (24).

With a collection of 1770 lip prints, a method had to be devised for analysis. Vast potential was discovered in this study, but due to time constraints, focus was placed on

Phase I. A database was created in AFIX Tracker containing 300 scanned images from Phase I. The author has experience with AFIX Tracker for the analysis of fingerprints, which greatly contributed towards defining rules towards mark-up of “minutiae”. For example, AFIX Tracker uses a coordinate system considering x, y, and orientation. When searching, the system ignores the image itself and focuses on the plotted minutiae in regards to spatial and directional positioning. Minutiae marked-up on a fingerprint that is typically recognized by AFIX Tracker’s algorithm, primarily includes bifurcations and ridge endings with special tools for each type. A goal of this study was to produce minutiae mark-up rules that were defined in a way that could be reproduced by other examiners.

All 300 photographs taken prior to utilizing the tape lift method were manually examined for minutiae, or potentially unique identifying characteristics. Certain minutiae stood out and included: bifurcations, curvatures, diamonds, dots, ending ridges, grids, middle horizontals, open-ended verticals, single horizontals and triangles. Five of which: curvatures, dots, ending ridges, grids, and open-ended verticals, were not considered in the final plan of mark-up for the following reasons.

First, curvatures were ignored because the author was aware of the AFIX Tracker algorithm to perform straight minutiae analysis, but unaware of its capabilities pertaining to curving minutiae. Moreover, the rare curvatures found were suspected to be debris (i.e. fuzz, dust, hair) instead of an actual groove within the Klein’s zone (Fig. 4). More impressions will have to be collected from the particular individual. If curvature was found to be a legitimate characteristic, it should not be ignored due to its rarity increasing significance. Second, dots were found between and within groove lines, especially at

points of intersection. Therefore, they were too abundant with varying factors of location, size and shape, causing issues with mark-up reproducibility. Third, ending ridges were comparative to fingerprints with a line abruptly stopping in space. However, the expression of lips has great impact on the characteristics found. Also, depending on the quality, ending ridges could continue and connect with an adjacent characteristic forming a triangle for instance, or continue and become an open-ended vertical Type. This uncertainty caused ending ridges to be temporarily ignored by the established mark-up rules. Fourth, grids or reticular patterns mentioned by past experts were found. These intricate patterns were suspected to be too complex for the current algorithm in AFIX Tracker. However, within the grids, other pattern such as triangles and diamonds were found and marked-up respectfully. The fifth Type of minutiae not considered was open-ended verticals. This Type of minutiae was too abundant with hard to define ends since the ends flow into space. This caused issues with mark-up reproducibility similarly to dots. Again, rules of mark-up were established to provide a reliable, reproducible method of testing AFIX Tracker's potential for individualization.

Kasprzak stated the following in his article, "Possibilities of Cheiloscopy" (40).

Research carried out abroad usually terminated in the stage of group classification and ended with a statement that the trace may be useful for personal identification. That is, however, insufficient for criminalist practice – the problems of how to carry out such an identification must be solved, and methods and techniques must be worked out.

5.4 Results

A survey of 11 questions was sent to 63 CBD-IAI members, resulting in an approximate 45% response rate. The gathered responses provided insight towards

relevant and practical materials and methods for the handling of this type of evidence. For instance, frequent mention of glass as a medium, black powder as a developer and lifting tape as an extraction method shaped a research idea into this relevant study. Furthermore, lip prints were found to be uncommon, but again, is this due to the lack of physical lip prints or lack of discovery and acknowledgement of lip prints? Interestingly, when this type of evidence was found, the majority of the responding agencies did not discover lipstick prints. Yet, most research being conducted purposely utilizes lipsticks for their production of lip prints. However, of important note, although the majority failed to discover lipstick prints, these were the agencies claiming to have only encountered lip prints one time.

The results of the survey were presented at the spring 2009 CBD-IAI conference in an attempt to generate more discussion and interest for this particular study and for lip print identification, in general. Following the presentation, three main suggestions were given from the FBI. First, Meagher suggested a collection that is more practical to casework by developing latents on a variety of items in a random fashion. While this is a very good proposition, the amount of tangible research on lip print identification is deficient. There is a need to build foundations through basic research before more complex ideas can be implemented. The results of the survey overwhelmingly stated glass being the medium in 100% of the cases with small mention of other substrates. A focus on glass still provides a relevant approach when also considering the common crimes being “peeping tom” and breaking and entering cases in which glass is an obvious a barrier. Secondly, Reznicek proposed family studies. Reznicek was informed how this had been done before in a limited fashion. In recall, Suzuki and Tsuchihashi studied twins finding lip prints were

alike with their characteristics being inherited from either one of their father or mother (16). Furthermore, she was informed that genetics would not be the scope of the study especially considering the limitation of sampling from a university. Finally, another analyst suggested further study into the physiological aspects of lips. While important, basic physiological aspects have already been defined (8). A study into the physiological aspects would be a challenging study in itself.

Before devising mark-up rules, the following minutiae were recognized when studying the PHASE I database for frequency analysis: bifurcations (up, down, diagonal), diamonds/triangles, dots, grids, middle horizontals, single horizontals (“singles”), and open-ended verticals. Curvatures and ending ridges were not considered for frequency analysis due to reasons mentioned previously. Dots, grids and open-ended verticals were originally included due to the author’s inexperience with lip prints. Experience changed the author’s outlook by ignoring the above minutiae due to issues with mark-up reproducibility. In addition, experience led to the consideration of “singles” and grids as one type, horizontals. At times, due to the intricacies of the lip prints, it was difficult to distinguish the two types (Fig. 47). For instance, when does a random single, horizontal line become intricate enough to be considered a grid formation? Whether the minutiae found was intricate enough to be considered “grids” or not, horizontal lines were always found.

FIG. 47—*Confusion of Singles and Grids.*

On the other hand, the author feels there could be significance in focusing on the upper lip below the philtrum for the presence of single horizontal lines. Dependant on clarity, middle horizontals appeared in all individuals studied. At first individual 12 did not seem to produce middle horizontals. Fortunately, the same individual was selected for Phase II. Upon examining photographs under Phase II with increased clarity, middle horizontals were found. At this point in research, intervariability seemed to be higher than intravariability in this area, which is needed for discriminatory purposes (Fig. 48).

FIG. 48—*Individual 4 and 29 - Presence of Middle Horizontals with Obvious Intervariability.*

In the bottom photograph of Figure 42, the details within the lip seem to be more intricate than the top photograph. Some individuals provided more intricate latents than others. It was difficult to determine the frequency of intricate vs. non-intricate lip prints. When does a lip print have enough detail to be considered “intricate”? Did the individuals convey different expressions?

Besides middle horizontals, bifurcations, diamonds and triangles were considered in the rules for mark-up. Like fingerprints, bifurcations were also found within lip prints under the same definition. Originally, the frequencies of bifurcations were separated based on directionality: up, down, and diagonal. With experience, this act was determined to be unnecessary. Diagonal was difficult to distinguish by itself. Again, the mobility of lips could alter the appearance of such characteristics. Bifurcations were found pointing in all directions in upper and lower lips for all individuals. Interestingly,

there was a tendency to have bifurcations open up towards the edges of the lips, but this includes the bottom portion of the upper lip having downward bifurcations and is not specific to the lower lip itself. At this time, it is unknown if “up” bifurcations are more frequent in the upper lip and “down” bifurcations are more frequent in the lower lip. Due to inexperience, diamonds and triangles were considered together for frequency analysis. A re-analysis should be performed with a separation of the two Types. The greatest limitation and frustration was the frequent occurrence of poor quality within the lower lip (Fig. 49). This also gives strength to the necessity of producing multiple impressions for an individual.

FIG. 49—*Limitation: Inexistent / Low Quality Lower Lip.*

In discussing AFIX Tracker reliability, SOM for LIC was tested with partial data from Phase I. 10 individuals with 3 impressions each for 4 different Types of minutiae results in the analysis of (10 x 3 x 4) 40 individuals and 120 lip print impressions.

Individuals were selected at random. If all three impressions were found to have the specific Type of minutiae, it was used in this study. For instance, if a situation was found such as Figure 43, this individual would not be used. The next random individual would be analyzed.

In utilizing Excel, the following calculations were determined: # Matched Minutiae, True Positive (TP), True Negative (TN), False Positive (FP), False Negative (FN), True Positive Rate (TPR), False Positive Rate (FPR), True Negative Rate (TNR), False Negative Rate (FNR), Area Under Curve (AUC), Sensitivity, Specificity, Selectivity, LR^+ , LR^- , $\text{Log}(LR^+)$, and $\text{Log}(LR^-)$. TP, TN, FP and FN have been discussed in detail in *Chapter I*. TPR is the determined rate of making a TP decision, or a correct inclusion. FPR is the determined rate of making a FP decision, or an incorrect inclusion (Type I Error). In an ideal situation, TPR would be high and FPR would be low. AUC is calculated to determine if the chosen method was “good” or not for discriminatory purposes and is expressed through ROC curves. A score of one, following the left and upper axes, represents a perfect classifier (41).

Likewise, TNR is the determined rate of making a TN decision, or a correct exclusion and FNR is the determined rate of making a FN decision, or an incorrect exclusion (Type II Error). Sensitivity, or TPR, is a way of determining how easily or fast detection is found. Specificity is a way of determining precision of a detected value. Selectivity deals with the ability of detection. Sensitivity and Specificity describe the true performance with greater clarity than accuracy (41). These two components are used to determine the positive and negative likelihood ratios. A positive likelihood ratio

represents the likelihood of a match and a negative likelihood ratio represents the likelihood of a non-match.

Previously mentioned, Type I errors (FP) and Type II errors (FN) are points of focus, with Type I errors given more consideration. AFIX Tracker was utilized to determine where these errors occur for the four Types of minutiae defined within the established method.

For all Types, with an increase in number of matched minutiae, there is a strong increase in TN, correct exclusions, and strong decrease in FP, incorrect inclusions. Therefore, Type I errors decrease. This occurs because Specificity increases with an increase in number of matched minutiae. Specificity detects a match (+), when in fact, it is a match. In other words, with increasing Specificity (detecting + when +), this will decrease FP (detecting + when -).

Moreover, FN, incorrect exclusions, slightly increase as TP, correct inclusions, slightly decrease. This observation may seem odd, but consider, a smaller quantity of information (lower number of matched minutiae) leads to more potential matches. Previously explained, Specificity increases with an increase in number of matched minutiae. Conversely, Sensitivity decreases. Sensitivity detects a non-match (-), when in fact, it is a non-match. Therefore, as Sensitivity decreases (ability to detect - when -), FN (detecting - when +) will inevitably increase. More focus needs to be placed on FP and ensuring this is zero before FN is considered. In fact, in studying the *Byron Mitchell* case, the error rate was a factor of concern (42). The court said, “in the courtroom, the rate of FN is immaterial to the *Daubert* admissibility of latent fingerprint identification offered to prove positive identification because it is not probative of the reliability of the

testimony *for the purpose for which it is offered* (i.e., “for its ability to effect a positive identification”) (42). In regards to FP, the court concluded that, “where what is sought to be proved is essentially a negative (i.e., the absence of false positives) it seems quite appropriate to us to use a burden-shifting framework” (42). Even though the error rate may not be precisely quantified, the court was persuaded that the methods of estimating it show it to be very low.

Discrimination is a combination of both Specificity and Sensitivity. It is a “give-and-take” relationship. Ideally, forensically speaking, there is a need for a high Specificity (detecting + when +) and a high Sensitivity (detecting – when –), which lies somewhere in-between the extremities of the graphs.

With this in mind, it is important to recognize when FP, Type I errors start to decline and when they minimize at zero. For diamonds and the number of matched minutiae, FP starts to fall from 3 to 9 minutiae. This means the analyst must be extra cautious when reaching the conclusion of a “Match” or individualization within this range with respect to diamond Type mark-up. For middle horizontals, the range of caution expands even more from 3 to 12 minutiae. Triangles and bifurcations have the same caution range from a smaller range of 3 to 8 minutiae. The lower boundary of 3 minutiae was common to all Types, strongly urging the examiner to not make a decision based on 1 or 2 minutiae. However, it is still possible to conclude a correct individualization within the ranges of caution due to factors such as the high quality and quantity of information available.

Previously defined, high Specificity (detecting + when +) will decrease FP. To have at least moderate Specificity and tolerable Sensitivity (where FN=FP), the number of

matched minutiae of concern in order of diamonds, middle horizontals, triangles, and bifurcations, occurs at approximately 7.5, 9.5, 6.75, and 6.75 minutiae, which must be rounded up to whole minutiae: 8, 10, 7, and 7 minutiae. Overall, middle horizontals continuously required more matched minutiae than the other three Types. For diamonds, triangles, and bifurcations, Sensitivity becomes lower than Specificity starting at 5 minutiae. However, this does not occur until 7 minutiae for middle horizontals.

For all Types, with an increase in match score, the same trends mentioned above were present. Ranges of caution can also be determined based on the match scores corresponding to where FP starts to decline and where FP ultimately reaches zero. Values of these focal points were mentioned in *Chapter IV*. Since the trends were found to be similar to “the number of matched minutiae” analysis, more focus was placed on minutiae numbers rather than match scores. At present, this seems to be more practical. To examine a lip print, an examiner would likely mark-up minutiae points. At which time, the analyst can keep in mind the determined ranges of caution. Later, if a database is established like the Integrated Automated Fingerprint Identification System (IAFIS), the match scores may play a more significant role. An outstanding high score (unknown threshold at present time) may result in an automatic individualization. Match scores below this threshold would need human assistance to reach a conclusion.

To recall, ROC curves express AUC summation values to determine if the method was “good” for discriminatory purposes or not with a score of 1 being perfect, 0.5 being non-discriminatory, and 0 being poor (41). The list of best to worst methods based on these summations for matched minutiae was as follows: bifurcations, middle horizontals, diamonds, and triangles. Yet, the Types were still not necessarily “good”. Bifurcations,

considered the best method, had a score of approximately 0.735. The following figure approximates the likelihood ratios based on this ROC curve for the number of matched minutiae (Fig. 50).

FIG. 50—Bifurcations: Receiver Operating Characteristics (ROC) Curve for Matched Minutiae with LR Trends.

The blue curving line represents the AUC result of approximately 0.735, which falls above the 0.5 black, solid, boundary line of discrimination. The best odds ratio was determined to be approximately 93 resulting from 9 matched minutiae. This means it is 93 times more likely to be a match than a non-match. In fact, the quadrant containing 9 minutiae is where $|\text{Log}(\text{LR}^+)| > |\text{Log}(\text{LR}^-)|$. Therefore, within this quadrant, there is a greater likelihood to get a match when it is a match with increasing positive likelihood ratios. The other quadrant indicates the $|\text{Log}(\text{LR}^-)| > |\text{Log}(\text{LR}^+)|$, which is where the number of matched minutiae below 5 are plotted. Thereby, there is a greater likelihood to get a non-match when it is a non-match with increasing negative likelihood ratios. The

best odds ratio was not greater than 9 minutiae because the FPR rate was found to stay the same or diminished to zero for minutiae greater than 9 and therefore could not be detected when zeros were entered into the equations.

A further look into likelihood ratios resulted in figures like the following (Fig. 32).

FIG. 32—Bifurcations: Evaluation of LR^+ and LR^- with Respect to the Number of Matched Minutiae.

The solid line represents $LR^+ = LR^-$. As we move to a greater number of minutiae to effect a match, the $\text{Log}(LR^-)$ decreases whilst the $\text{Log}(LR^+)$ increases. There is a larger likelihood ratio when moving up the line with the slope of the line being a measure of the odds ratio.

Focus has been placed on bifurcations since this was the best method found for discrimination. Triangles, considered the worst method, had a score of approximately 0.48. For match scores, AUC summations were all above 0.5 with middle horizontals trading positions with bifurcations. The author hypothesizes reasons for these results.

AFIX Tracker's algorithm primarily handles bifurcations and ridge endings with special tools for each Type when considering fingerprints. The best results when considering lip prints were those relative to these Types: bifurcations (used bifurcation tool) and middle horizontals (used ridge ending tool). The number of marked-up minutiae per latent should be considered. Perhaps middle horizontals had a better ROC curve than bifurcations for match scores because more bifurcations were marked-up, distracting the system. The author also hypothesizes the four Types of minutiae will be more discriminatory in combination with each other. Different combinations of the proposed four Types should be tested. A certain Type, perhaps triangles with the lowest score, could be found to hinder the searching process. Moreover, the average results obtained in this current study could be due to auxiliary assumptions. Conceivably, a revision to the SOMS for LIC is necessary to achieve a better result.

As forensic scientists, we must remember that we can only work with what we are given. There are obvious limitations (i.e. sample size, etc.) towards this study. However, ranges of caution were defined for all four Types. A decision is not necessarily dependant upon a magical number of minutiae, but the quality and quantity of information. In fact, the absence of a characteristic is a characteristic in its own right. In addition to the ranges, another focal point was determined where non-matches stopped occurring with respect to the number of matched minutiae. These values were even higher than the upper boundary of the cautionary ranges. Therefore, a range of caution is not definitive and should not be treated as such.

Although bifurcations appeared to be the best mark-up plan, the percent frequency of finding both true matches within the top 25 candidates was only 46.7% and finding zero

true matches was at a high of 20.0%. Diamonds, the third place method winner, and middle horizontals had a 76.7% frequency for finding both true matches. Triangles still seemed to fall into last place with 36.7% frequency and having the lowest maximum number of matched minutiae, which was 10 compared to 12 and 15 minutiae from the other Types. Triangles only achieve first place with determining the percent frequency of finding one of the two true matches within the top 25 candidates with 43.3%.

5.5 Conclusion

The purpose of this study was to promote awareness of lip print identification. Fact: Lip print evidence has already been inside the courtroom (32). Fact: The FBI once believed in its power for individualization (39). Fact: The National Academy of Sciences acknowledges lip prints as a type of impression evidence (11). Fact: The author's intent of this study was not to stimulate a premature use of lip print identification / individualization in actual casework, but simply to stimulate research and testing. In doing so, this study fulfilled a second purpose of testing the reliability of AFIX Tracker for lip print individualization. The reader may not agree with the opinions of the author, but this study was conducted over 2 years, which credits the author with perhaps not an "expert" title, but surely more of an "expert" than most readers. Controversy is what keeps forensic science alive and growing. If lip prints are ever to have the chance of becoming generally accepted under basic *Frye* requirements, it takes scientists like the author to push through the smirks of indolent, unbelievers. As overwhelmingly complex lip prints can be, one has to at least wonder if lip prints are truly unique or if such intricate patterns could be completely replicated in different individuals.

This study, “Preliminary Study on the Reliability of AFIX Tracker for Lip Print Examination”, is just that, a preliminary study. 1770 lip prints were collected, including 100 individuals, providing vast potential for analysis. Future analysis may involve a further look into past studies outlined in the literature review of this paper. Is the dental formula worth using? Will the results be verified? What other results will be disproven? Is there a greater tendency of “up” bifurcations within the upper lip? Future analysis will involve a more thorough look into intravariability through persistence in Phase II, with consideration of winter and fall seasons. For at this time in the study, the author cannot say if changes did or did not occur in lip print patterns with change in time. Likewise, at this stage, it cannot be said if all individuals produced different lip prints. However, the power of exclusion seems likely, if persistence could be established. The author can agree with past experts that lip prints contain more than one Type of characteristic (6), but at this present time, urges caution towards comments such as the following:

Cheilosopic techniques have an equal value in relation to other types of forensic evidences for personal identification (21).

This research provides awareness of lip print examination. Readers are encouraged to continue research by “kissing controversy goodbye”.

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APPENDICES

Appendix A

TABLE A1—Survey Sent.

Evaluation of lip prints evidence in caseworks

1. How common are lip prints in your agency? If possible, provide some numbers (even estimations). Example: Number of cases per year or over a longer period of time.
2. What is the ratio between the analysis requests on lip prints and fingerprints? If possible, provide some numbers (even estimations). Example: 1 against 100.
3. When found, in what types of cases were lip prints recovered? [i.e. Homicide, B&E]
4. When found, what type of support was involved? [i.e. paper, glass]
5. When found, were cosmetics involved?
 - c. If yes, what type?
 - d. If yes, did this alter your method of collection? In what way?
6. When found, was there an appearance of overlapping?
 - e. If yes, is this a common occurrence?
7. When found, what is your method of collection?
8. What is your method of processing and analyzing?
9. Did you ever feel lip prints could have been critical to a case?
10. Do you feel that lip print identification could be useful if standards were established?
11. Do you only focus on patent lip prints or do you consider a search of latent lip prints?

TABLE A2—*E-mail Sent.*

Date

Agency Name
Agency Address

Dear CBD-IAI Member,

As a recent graduate of West Virginia University, I have earned a Bachelor's of Science degree in Forensic & Investigative Sciences with an emphasis in Examiner. This prestigious program has persuaded me to further my education with a Masters of Science.

One of the graduation requirements involves research. Due to my interest in fingerprint identification, I have decided to expand on similar concepts and study impression evidence involving lip print identification. If interesting results are obtained, it will be my intention of submitting this research for presentations at conferences of the Chesapeake Bay Division of the International Association for Identification. My professor Dr. Patrick Buzzini and I decided to distribute a survey for CBD-IAI members to determine an appropriate direction for our study. Currently, the main focus is to study the variability between individuals and within the same individual lip prints. Our goal is to explore the potential evidential value of this less commonly encountered type of evidence.

Therefore, we are requesting your help for obtaining some global information about the examination of lip prints in your agency. Your contribution will be very useful to understand the important points for orienting our research, so that we can attempt to focus our directions toward a practical interest for examiners. Please, fill out the attached survey. Answers can be directly typed into the word document. Input and ideas are very much appreciated. If you have questions and need further information, please do not hesitate to ask. Please send completed survey to the e-mail address below. Thank you for your time.

Sincerely,

Kelli E. Edmiston

Contact Information

TABLE A3—*Reminder E-mail Sent.*

Date

Agency Name

Agency Address

Dear CBD-IAI Member,

This e-mail is a reminder that I am in need of responses for my future research and more importantly, for my presentation at the upcoming Chesapeake Bay Division conference entitled, “Kissing Controversy Goodbye: Known Truths of Lip Print Identification”. I will keep all of the information you provide (examiners, agencies, etc.) confidential. If a specific case or situation deserves to be exposed or discussed in public, I will specifically request formal permission.

Sincerely,

Kelli E. Edmiston

Contact Information

Appendix B

FIG. B1—*Individual 7 Thrown Out of Study during Phase I.*

Appendix C

TABLE C1—Collection Schedule of Fifty Volunteers for Phase II.

Collection Date: 10/19/09

Week #1

MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	SUNDAY
	1	6	8	13	19	21
	2	7	9	14	20	22
	3		10	15		23
	4		11	16		24
	5		12	17		25
				18		

Week #2

MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY	SUNDAY
26	31	36	38	43		49
27	32	37	39	44		50
28	33		40	45		
29	34		41	46		
30	35		42	47		
				48		

Appendix D

TABLE D1—*Mark-up Rules (SOM for LIC).*

STANDARD OPERATING MANUAL [1] **(SOM)**

LIP PRINT IMAGE COMPARE (LIC)

Automated Fingerprint Identification System
[AFIX Tracker]
Version 5.0.0.77

Revised: 01/28/10

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DISCLOSURES

SOM for LIC was created based on a study of 100 different individuals providing 3 impressions each. Identifying characteristics were noted but may not provide the robust foundation needed for lip print identification due to the limitation of 300 impressions studied.

Mark-up is dependant upon David Ashbaugh's explanation of Analysis for ACE-V with respect to selecting quality worthy identifying characteristics [2].

It is recommended to invert images prior to the mark-up of identifying characteristics to portray black ridges similar to that of fingerprints.

BIFURCATIONS

According to the Science of Fingerprints, a bifurcation is, “the forking or dividing of one line into two or more branches” [3]. Bifurcations are found in lip prints pointed in directions of up, down, and/or diagonal.

LIC:

1. **Locate** bifurcations in upper and lower lips.
2. **Ignore** grid areas (too abundant).
Give priority to dominant bifurcations that appear on thickest **OPEN-ENDED VERTICALS**. Continue mark-up of other bifurcations as needed.
3. Mark-up bifurcations with **purple** tool with respect to directionality.

CURVATURES

Although uncommon, lip prints can contain points of curvature.

LIC:

1. **Ignore** areas of curvature.
2. Although rarity increases significance, AFIX capabilities are limited. Curvature in the future should not be ignored, but a different algorithm must be established before mark-up can occur.
3. Curvature can be used in a comparison by the examiner.

DIAMONDS

Lip prints may have intersecting grid lines that form diamond shapes.

LIC:

1. **Locate** diamond shapes in upper and lower lips.
2. Treat diamonds as **four bifurcations**.
3. Diamonds found must be **well defined** with sharp angles (i.e. no curvature).

DOTS

Dots are found in all lip prints between and within lines, especially at points of intersection.

LIC:

1. **Ignore** dots.
2. Dots are too abundant and vary in location, size and shape similarly to that of poroscopy in fingerprints. Contrary to fingerprints, dots are more readily found in lip prints and do not rely as heavily on clarity to be visible.
3. Dots may be used as third level detail in a comparison by the examiner.

ENDING RIDGES

Ending ridges may be found in lip prints when a line abruptly stops in “space” within the Klein’s zone [4].

LIC:

1. **Ignore** ending ridges.
2. Ending ridges could continue and connect with an adjacent characteristic or continue and become an open-ended vertical Type. Differences could be found due to the quality of the latent and expression of the lips.

GRIDS

Intricate patterns may be found and could involve grid-like patterns with intersecting vertical and horizontal lines.

LIC:

1. **Ignore** grids themselves.
2. **Look** for discrete patterns within for mark-up (i.e. diamonds, triangles, etc.).
3. Grids create intricate patterns that may be too complex for the algorithm used in AFIX Tracker. Grids in the future may not be ignored if a different algorithm is established for recognition to occur.

MIDDLE HORIZONTALS

The upper lip may have horizontal, parallel lines directly in the middle of the impression.

LIC:

1. Focus on **upper** lip.
2. **Locate** the ending ridges of the horizontal middle.
3. Mark-up distinct ending ridges with **red** tool appropriately.

OPEN-ENDED VERTICALS

Open-ended vertical lines are found in all lip prints extending from the outer to inner edges.

LIC:

1. **Ignore** open-ended verticals.
2. Open-ended verticals are too abundant and vary in location, size and shape similarly to that of edgeoscopy in fingerprints.
3. Open-ended verticals may be used as third level detail in a comparison by the examiner.

SINGLE HORIZONTALS

Lip prints may not have intricate grid lines but instead, single horizontal lines.

LIC:

1. **Ignore** single horizontal lines (**except** single **MIDDLE HORIZONTALS** of upper).
2. Single horizontals are difficult to clearly distinguish from grids and typically form other identifying characteristics that have a defined mark-up (i.e. bifurcations, triangles, etc.).

TRIANGLES

Lip prints may have intersecting grid lines that form triangle shapes.

LIC:

1. **Locate** triangle shapes in upper and lower lips.
2. Treat triangles as **three bifurcations**.
3. Triangles found must be **well defined** with sharp angles (i.e. no curvature).

REFERENCES

- [1] FBI: Tenprint Processing Services. *Standard Operating Manual: Fingerprint Image Check/Fingerprint Sequence Check for IAFIS*. Version 1.0. Revised 02/28/2008.
- [2] Ashbaugh, D. (1999). *Quantitative-Qualitative Friction Ridge Analysis: An Introduction to Basic and Advanced Ridgeology*. Chapter IV: The Identification Process. CRC Press LLC.
- [3] Department of Justice: FBI. *Science of Fingerprints*. Bifurcation definition. pg 8.
- [4] Scully, C., Bagan, J. V., Eisen, D., Porter, S., & Rogers, R. S. (2000). *Dermatology of the lips*. Oxford: Isis Medical Media Ltd.

Appendix E

TABLE E1—*Informed Consent.*

CONSENT AND INFORMATION FORM

LipPrints collection

Principal Investigator: Buzzini, Patrick
Department: ARTS & SCIENCES - Forensics
Tracking Number: H-21819

Study Title:

The reliability of AFIX Tracker for lip print examination

Co-Investigator(s):

Edmiston, Kelli

Sponsor

Forensic and Investigative Science Program of West Virginia University

Contact Persons

For more information about this research, you can contact Dr. Patrick Buzzini at (#) (email: patrick.buzzini@mail.wvu.edu) or Dr. Keith Morris at (#) (email: keith.morris@mail.wvu.edu).

For information regarding your rights as a research subject, you may contact the Office of Research Compliance at (304)293-7073.

Introduction

You, _____, have been invited to participate in research study supervised by Dr. Patrick Buzzini, assistant professor with the Forensic and Investigative Science Program of West Virginia University, and Dr. Keith Morris, director of the program. The research study has been explained to you by _____.

Tracking #: H-21819

Page 1 of 4

Approved On: 08/18/2009

Valid Through: 08/17/2010

Last Amended: N/A

initials

date

Purposes of the Study

This research intends to collect lip impressions from 100 different volunteers to evaluate objective methods for enhancing the current methodology for lip print examination in forensic science. The proposed method is based on AFIX Tracker and this software's ability to produce scores based on likeness. The scores can then be analyzed to determine error rates, which provides an insight to the variability of lip prints.

Description of Procedures

Lip prints are unique in much the same manner as fingerprints. However, they have not been extensively studied like fingerprints. The purpose of this study is to examine similarities and patterns among the lip prints of many individuals. This information may one day be used to help investigators solve crimes using lip prints. You will be asked to apply your lips, both the upper and lower lip simultaneously, to a 75 x 50 mm glass slide for 2-3 seconds. This operation may be requested a further time in the next future. Your lip impressions will be then dusted (like fingerprints) and analyzed by computer software (AFIX Tracker) with the lip prints of other individuals.

Risks and Discomforts

There are no known or expected risks from participating in this study, except for the potential anxiety from pressing lips against glass.

Alternatives

You do not have to participate in this study.

You understand that you do not have to participate in this study.

Tracking #: H-21819

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Approved On: 08/18/2009

Valid Through: 08/17/2010

Last Amended: N/A

initials

date

TABLE E1—*Informed Consent – Continued.*

Benefits

You understand that this study is not expected to be of direct benefit to you, but the knowledge gained will be of benefit to others (i.e. forensic science community).

Financial Considerations

There are no costs or rewards for participating in this study.

Confidentiality

You understand that any information about yourself obtained as a result of your participation in this research will be kept as confidential as legally possible. In any publications that result from this research, neither your name nor any information from which you might be identified will be published without your consent.

Voluntary Participation

Participation in this study is voluntary. You understand that you are free to withdraw your consent to participate in this study at any time and that such refusal to or withdrawal will involve no penalty to you. You have been given the opportunity to ask questions about the research, and you have received answers concerning areas you did not understand. If you are a WVU student, you understand that class standing or grades will not be impacted in any way whether or not you choose to volunteer in this study.

Tracking #: H-21819

Page 3 of 4

Approved On: 08/18/2009

Valid Through: 08/17/2010

Last Amended: N/A

initials

date

TABLE E1—*Informed Consent – Continued.*

Upon signing this form, you will receive a copy.

I willingly consent to participate in this research.

Signature of Subject or
Subjects Legal Representative

Printed Name

Date

Time

The participant has had the opportunity to have questions addressed. The participant willingly agrees to be in the study.

Signature of Subject or
Subjects Legal Representative

Printed Name

Date

Time

Tracking #: H-21819

Page 4 of 4

Approved On: 08/18/2009

Valid Through: 08/17/2010

Last Amended: N/A

initials

date

Appendix F

TABLE F1—*Spring 2009 CBD-IAI Abstract.*

Kissing Controversy Goodbye: Known Truths of Lip Print Identification April 2, 2009

Kelli Edmiston, graduate student, Forensic & Investigative Science Program, West Virginia University

Patrick Buzzini, assistant professor, Forensic & Investigative Science Program, West Virginia University

Compared to other types of impression evidence, lip prints have not been studied as extensively. Yet, it has been proposed that lip prints have the same power of individualization as fingerprints, in that they are both unique and persistent. Since lip print identification is still in the exploratory stage of research, how can anyone truly be an expert? Is the current state of research sufficient to claim uniqueness and persistency? Is it possible or even necessary to develop a classification system for lip prints as it is the case for fingerprints? As a corollary, how do these aspects reflect to the *Daubert* standards? During this presentation the current state of the knowledge on lip prints related to these questions will be reviewed. Additionally, more than sixty members of the Chesapeake Bay Division of the International Association for Identification (the majority of them we selected as a representative of their agency) were surveyed on this topic. The participants to this survey were asked about the occurrence of this type of evidence in their casework, the method of collection used and the methodology followed for their examination. The results will be implemented into this presentation.

Our intent is not to stimulate a premature use of lip print identification in actual case work, but simply to stimulate research and testing. Therefore, in order for lip prints to have a chance of becoming a useful type of evidence, an agreement has to be made with its reliability including any methodologies, which in return, means more discussion and research is required.

Kissing Controversy Goodbye: Known Truths of Lip Print Identification

[1]

Kelli E. Edmiston

Graduate Student
West Virginia University

[1] ZengerBlog. (2008). Happy Friday! Retrieved November 10, 2009, from: http://www.zengerblog.com/glimmer_scorpio_lips.htm

The **PURPOSE** of this presentation is to generate discussion about lip print identification.

Intent is not to stimulate a premature use of lip print identification in actual casework, but simply to stimulate research and testing.

"If we are trained to ignore morphological shapes or forms, such as ridge edges, ridge pores or creases, then they will have little or no significance." [2] ~ Grieve

[3]

[2] Grieve, D. (1999). The Identification Process: TWOFAST and the search for science. *The Print - SCAPD*, 13 (2).
[3] Sacramento, R. (2008). *Leading Lipstick*. Retrieved March 18, 2009, from: www.blogsida.com/~2000116/0115_red_lips.jpg

This presentation examines what has been done in the past and what may be done in the future.

1. Background
2. Experts
3. Studies
4. Research

[4]

[4] British Telecommunications PLC. (2008). *Oral Scott*. Retrieved March 17, 2009, from: www.britishtel.com/~J02/back_future_450.jpg
[5] O'Connor, K. (2004). *Arasau White*. Retrieved March 17, 2009, from: www.arasauwhite.com/first/firstpage/first470.jpg

It is possible to identify lip patterns during the sixth week of uterine life.

"Cheiloscopy"

"Lip prints are **UNIQUE** to one person, except in monozygotic twins." [6]

[6] Calkins, L. M., Magalhães, T., and Adams, A. (2007). Establishing identity using cheiloscopy and palatoscopy. *For Sci International*, 16, 1-9.

Anatomically - lips are two, sensitive folds, composed of skin, muscle, glands and mucous membrane. [8]

→ orbicularis oris [8]

Horizontal, Elevated or Depressed

- 8 - 10 mm →
1. Thin (European Caucasians)
 2. Medium *(Most Common)
 3. Thick (African Americans)
 4. Mix (Orientals)

MEN

WOMEN

[7] Hushell Studios. (2004). *Howe and Lips*. Retrieved November 10, 2009, from: www.hushellstudios.com/~howeandlips.gif
[8] Calkins, L. M., Magalhães, T., and Adams, A. (2007). Establishing identity using cheiloscopy and palatoscopy. *For Sci International*, 16, 1-9.
[9] Sealy, C., Bagan, J. V., Egan, D., Foster, S., & Rogers, R. S. (2000). *Dermatology of the lips*. Oxford: Isis Medical Media Ltd.

Like fingerprints, lip grooves are permanent and unchangeable. [9]

Lip groove patterns **RARELY** change, resisting many afflictions.

[9]

[9] ADAM, Inc. (2000). *Chapped lips*. Retrieved November 10, 2009, from: www.adaminc.com/~body/00/0004/0172_en.jpg
[10] Calkins, L. M., Magalhães, T., and Adams, A. (2007). Establishing identity using cheiloscopy and palatoscopy. *For Sci International*, 16, 1-9.

Lipstick may provide cell remains from which DNA can be extracted.

"Results indicated that latent lip prints on paper developed with Sudan Black can be used as a potential DNA source for forensic identification."^[19]
~ Ana Castelló

[19] Castelló, A., Alvarez, M. and Tschü, F. (2004). Just lip prints? No there could be something else. *PASER Journal*, 13, 615-616.
[20] Wikipedia. (2007). *Crestore Cosmetics*. Retrieved November 10, 2008, from: http://3.bp.blogspot.com/_x6320/Lipstick_on_Lips.jpg

Since Daubert, the limitations of lip print examinations have been reassessed.

3D → 2D

- Expert = ?
- Mobility of lips
- Post-mortem changes in lips?
- Persistency: Temporary alterations
- Uniqueness: Except in monozygotic twins?

"Cannot study all lips"

TIME
MONEY
EFFORT
PRECISION
ACCURACY
SELECTIVITY

[21] Flickr. (2007). Retrieved November 6, 2008, from: [http://flickr3.static.flickr.com/2313/1529777396_783e674ef.jpg](http://images.google.com/images?imgref=http://flickr3.static.flickr.com/2313/1529777396_783e674ef.jpg)

The survey gathered opinions in order to determine an appropriate direction for research.

28
63 E-mails Sent

11 Questions Asked

"I will keep all of the information you provide (examiners, agencies, etc.) confidential. If a specific case or situation deserves to be exposed or discussed in public, I will specifically request formal permission."

[22] CBD-IAI. (2009). Retrieved November 10, 2008, from: <http://www.cbdiu.org/>

How common are lip prints in your agency?

Most Common: "Never had a lip print case" 64%

In what types of cases were lip prints recovered?

"Robberies"
"B&E's"
"Homicides"

[23] Pinner, M. (2009). *Corbis*. Retrieved March 13, 2009, from: <http://images.google.com/images?imgref=http://pe.corbis.com/images/40155.jpg>

FIG. F1—Spring 2009 CBD-IAI Presentation – Continued.

What medium was involved?

[24] Young, C. (2003). *Looking the Window*. Retrieved March 13, 2009, from http://images.google.com/images?imgref=http://www.123rf.com/2014/06/100_44496177.jpg
 [25] Holsted, S. (2009). *Cosbar*. Retrieved March 13, 2009, from <http://images.google.com/images?imgref=http://www.cosbar.com/images/A2061941.jpg>

Were cosmetics involved?

Most Common: "No"

"Mostly with lipstick" ~ Some
 "Sometimes with lipstick" ~ Several

[26] [Unlabeled image lipstick and lips]. Retrieved March 13, 2009, from www.istockphoto.com/stock-photo-2009/istockphoto-2009.jpg

What was your method of collection?

"I collected lip print standards using both the substrate involved as well as lipstick and white paper, taking **numerous** samples from the subjects."

Black Powder → Photograph → Lift
 Swab for DNA

What was your method of processing & analyzing?

Most Common: "No analysis took place"

"I would follow ACE Methodology"

Porous?
 Nonporous?

"DNA would be top priority in the analysis. If no DNA resulted and a suspect is known, might ask lab to analyze it, comparing it to a known that was given by consent, but we usually use it as a tool for interviewing yielding confessions."

[27] DNAbase. (2009). Retrieved March 13, 2009, from www.dnabase.com/images/mousepad/DNA1h.jpg

Did you ever feel lip prints could have been critical to a case?

"Not critical, numerous fingerprints were developed with several being identified to a subject."

"I was sure that the lip impression could have been useful, but it was an examination for which I was not trained to perform."

[28] Dawkins, M. (2009). *Lighter Photos*. Retrieved March 13, 2009, from http://images.google.com/images?imgref=http://static-p4f.istock.com/0004/04/04_04_F_4965981.jpg&imgref=http://static-p4f.istock.com/0004/04/04_04_F_4965981.jpg&imgref=http://static-p4f.istock.com/0004/04/04_04_F_4965981.jpg

Do you feel that lip print identification could be useful if standards were established?

"Absolutely. I'm confident that lip prints have individualizing value, but **research must be conducted** and evidence of uniqueness fully established before it could pass Daubert standards."

"No, DNA would be better with an already established database."

"Standards alone without substantial research and validation of the science will not suffice."

[29] Bennett, C. (2008). *Overlaid*. Retrieved March 13, 2009, from www.cdfeducation.com/~K2/overlaid-211x308.jpg

FIG. F1—Spring 2009 CBD-IAI Presentation – Continued.

The Game Plan:

100+ Subjects

- Variety in Age
- Variety in Gender
- Variety in Cosmetics

6+ Impressions

- Variety in Pressure
- Variety in Expressions

Uniqueness & Persistence

"Fingerprints only became a useful tool of forensic science when a workable method of classification was developed."^[30]

~ Robertson

[30] Robertson, B. (1992). John Wiley & Sons, Chapter 5: Transfer Evidence, Pg. 137.

[31] Steven Schmitt/Getty Images (2008). Retrieved March 17, 2009, from: www.sportsillustrated.com/ /Bob-Whipple.jpg

In order for lip prints to have a chance of becoming a useful type of evidence, an agreement has to be made.

Most Common: "Never had a lip print case" **64%**

"The frequency of occurrence of certain evidence types does not necessarily correlate positively with the inherent value of the evidence."^[32]

~DeForest

More research is needed!

QUESTIONS?

SUGGESTIONS?

[32] Fawcett, P. R. (2001). Brian Cuddy, Chapter 1: 'What is forensic evidence?' Pg. 24.

[33] FoxSports (2009). Retrieved March 17, 2009, from: www.foxsports.com/images/pics lip.jpg

Appendix G

TABLE G1—*Example of Pivot Table: Diamonds [Matched Minutiae vs. Match/Non]*.

Count of # Matched Minutiae	Match/Non-Match		
# Matched Minutiae	Match	Non- Match	Grand Total
0		8	8
2		9	9
3	7	182	189
4	16	256	272
5	7	102	109
6	5	71	76
7	8	42	50
8	2	19	21
9	2	3	5
10	13	4	7
12	2		2
Grand Total	52	696	748

TABLE G2—Example of Calculated Data: Diamonds [Matched Minutiae vs. Match/Non].

# Matched Minutiae	TP	TN	FP	FN	TPR	FPR	TNR	FNR	AUC
0	52	0	696	0	1.00	1.00	0.00	0.00	-
2	52	8	688	0	1.00	0.989	0.0115	0.00	0.0115
3	45	17	679	0	1.00	0.976	0.0244	0.00	0.0129
4	29	199	497	7	0.806	0.714	0.286	0.194	0.236
5	22	455	241	23	0.489	0.346	0.654	0.511	0.238
6	17	557	139	30	0.362	0.199	0.800	0.638	0.0623
7	9	628	68	35	0.205	0.0977	0.902	0.795	0.0289
8	7	670	26	43	0.140	0.0374	0.963	0.860	0.0104
9	5	689	7	45	0.100	0.0101	0.989	0.900	0.00328
10	2	692	4	47	0.0408	0.00575	0.994	0.959	0.000303
12	0	696	0	50	0.00	0.00	1.00	1.00	0.000117
									0.604

TABLE G3—*Example of Calculated Data: Diamonds – Continued.*

# Matched Minutiae	SENS	SPEC	SEL	LR+	LR-	Log(LR+)	Log (LR-)
0	1.00	0.00	0.0695	1.00	-	-	-
2	1.00	0.0115	0.0703	1.01	0.00	-	-
3	1.00	0.0244	0.0622	1.03	0.00	-	-
4	0.806	0.286	0.0551	1.13	0.680	0.0523	-0.167
5	0.489	0.654	0.0837	1.41	0.782	0.149	-0.107
6	0.362	0.800	0.109	1.81	0.798	0.258	-0.0982
7	0.205	0.902	0.117	2.09	0.882	0.321	-0.0547
8	0.140	0.963	0.212	3.75	0.893	0.574	-0.0489
9	0.100	0.989	0.417	9.94	0.909	0.998	-0.0414
10	0.0408	0.994	0.333	7.10	0.965	0.851	-0.0156
12	0.00	1.00	-	-	1.00	-	-

Appendix H

TABLE H1—*Summary of Intersections for Four Minutiae Types (Matched Minutiae).*

Model Component - Intersections (Matched Minutiae)

TP & TN	
---------	--

Middle Horizontals	3.25
Triangles	3.25
Bifurcations	3.00
Diamonds	3.00

TP & FN	
---------	--

Middle Horizontals	6.50
Bifurcations	5.00
Diamonds	5.00
Triangles	4.00

TN & FP	
---------	--

Middle Horizontals	5.25
Triangles	4.75
Diamonds	4.50
Bifurcations	4.25

FN & FP	
---------	--

Middle Horizontals	9.50
Diamonds	7.50
Bifurcations	6.75
Triangles	6.75

Specificity & Selectivity	
---------------------------	--

Middle Horizontals	3.25
Triangles	3.25
Diamonds	3.00
Bifurcations	3.00

Specificity & Sensitivity	
---------------------------	--

Middle Horizontals	6.00
Bifurcations	4.50
Diamonds	4.50
Triangles	4.50

Sensitivity & Selectivity	
---------------------------	--

Middle Horizontals	9.50
Diamonds	7.50
Bifurcations	6.75
Triangles	6.75

TABLE H2—Summary of Intersections for Four Minutiae Types (Match Scores).

Model Component - Intersections (Match Scores)	
TP & TN	
Diamonds	5532
Middle Horizontals	2925
Triangles	864
Bifurcations	666
TP & FN	
Middle Horizontals	36390
Triangles	20410
Bifurcations	17648
Diamonds	16496
TN & FP	
Diamonds	22788
Triangles	17795
Middle Horizontals	17469
Bifurcations	9306
FN & FP	
Diamonds	83850
Triangles	56506
Middle Horizontals	55089
Bifurcations	25542
Specificity & Selectivity	
Diamonds	5092
Middle Horizontals	2484
Triangles	846
Bifurcations	657
Specificity & Sensitivity	
Middle Horizontals	24408
Diamonds	26028
Triangles	18095
Bifurcations	11375
Sensitivity & Selectivity	
Diamonds	88714
Middle Horizontals	59159
Triangles	54236
Bifurcations	29349

TABLE H3—Summary of Max-Out Minutiae Values for Four Minutiae Types.

Max Out (Matched Minutiae)	
TP (0)	
Middle Horizontals	11
Diamonds	10
Bifurcations	9
Triangles	6
FN	
Bifurcations	-
Diamonds	-
Middle Horizontals	-
Triangles	-
TN	
Middle Horizontals	12
Diamonds	9
Bifurcations	8
Triangles	8
FP (0)	
Middle Horizontals	12
Diamonds	9
Triangles	8
Bifurcations	8
Selectivity	
Middle Horizontals	14
Bifurcations	12
Triangles	5
Diamonds	-
Specificity	
Middle Horizontals	12
Diamonds	9
Bifurcations	8
Triangles	8
Sensitivity (0)	
Bifurcations	15
Middle Horizontals	15
Diamonds	12
Triangles	10