RDT&E IWG Hair Analysis Questions

1. What literature exists that addresses the use of mtDNA analysis in conjunction with conventional morphological hair comparisons?

Houck, M. M., Budowle, B. (2002). Correlation of Microscopic and Mitochondrial DNA Hair Comparisons. *Journal of Forensic Sciences,* 47, 964-967.

The authors used data from human hairs submitted to the FBI Laboratory for analysis between 1996 and 2000. Of the 170 microscopical hair examinations, there were 80 associations, and of these, 9 were excluded by mitochondrial DNA (mtDNA) analysis. 66 hairs that were considered either unsuitable for meaningful microscopical analysis or yielded inconclusive microscopic associations provided meaningful mtDNA results. Only 6 hairs did not provide sufficient mtDNA and only 3 yielded inconclusive mtDNA results. Consistency was observed in the exculpatory results between the two procedures. This study demonstrates the utility of microscopical hair examinations and the strength of combining microscopic analysis with mtDNA sequencing.

Bisbing, R. E., Wolner, M. F. (1984). Microscopical Discrimination of Twins' Head Hair. *Journal of Forensic Sciences,* 29, 780-786.

Duplicate head hair samples from 17 pairs of twins and one set of triplets were compared in a blind study. Each hair sample was separated into two mounted slides, each containing 25 hairs. Using macroscopic and microscopic characteristics of the head hairs, the researchers were able to correctly associate the specimens with the duplicate sample and never with a twin. In a second part of the study, simulated forensic comparisons were performed. Seven tests were prepared where questioned hairs were compared to several randomly selected known samples. In this part of the study none of the known pools randomly selected actually contained the corresponding known sample from the questioned hair. In the seven tests, the first examiner correctly excluded 47 out of 52 samples and the second examiner correctly excluded 49 out of 52 samples. Although no DNA testing was conducted on the samples, it should be noted that all of the twins will have the same mitochondrial DNA and all of the identical twins will have the same nuclear DNA.

*It should be noted that throughout this study, the hairs were mounted only between two glass microscope slides. In a full microscopical analysis, the hairs would be mounted in a mounting media which allows for greater resolution of the microscopic characteristics.

Linch, C. A., Smith, S. L., Prahlow, J. A. (1998). Evaluation of the human hair root for DNA typing subsequent to microscopic comparison. *Journal of Forensic Sciences,* 43, 305-314.

Linch, C. A., Whiting, D. A., Holland, M. M. (2001). Human hair histogenesis for the mitochondrial DNA forensic scientist. *Journal of Forensic Sciences,* 46, 844-853.

Melton, T., Dimick, G., Higgins, B., Lindstrom, L., Nelson, K. (2005). Forensic Mitochondrial DNA analysis of 691 casework hairs. ***Journal of Forensic Sciences,*** **50, 73-80.**

Roberts, K.A., Calloway, C. (2007). Mitochondrial DNA amplification success rate as a function of hair morphology. ***Journal of Forensic Sciences*****, 52, 40-47.**

Sekiguchi, K., Hajime Sato, Kasai, K. (2004). Mitochondrial DNA heteroplasmy among hairs from single individuals.

2. What literature exists that evaluates and reports on the investigative value of hair evidence and the types of questions that can be answered by microscopic hair comparisons?

Robertson, J. (1999). Forensic Examination of Hairs. London: Taylor and Francis.

This text book covers aspects of hair examination including the microscopical comparison of hairs. Other chapters in this text include the growth and morphology of human hair, DNA derived from hairs, elemental analysis of hair, drug analysis using hair, cosmetic treatment that can be performed on hairs and finally a chapter on the evidential value of hair examinations.

Bisbing R. E. (2002). Forensic Science Handbook Volume 1 2nd Edition: Chapter 7 – The Forensic Identification and Association of Human Hair. Edited by Saferstein, R., New Jersey: Prentice-Hall Inc.

This text has chapters on many fields of forensic science. The chapter on human hair identification and association includes topics on hair structure, growth, identification and comparison, collection, conclusions and report writing and presentation of the evidence in court.

Hicks, J. W. (1977). Microscopy of Hairs: A Practical Guide and Manual. Issue 2. Washington, DC: Federal Bureau of Investigation.

Deedrick, D., Koch, S. L. (2004). Microscopy of Hair Part 1: A Practical Guide and Manual for Human Hairs. Quantico, VA: Federal Bureau of Investigation.

In an introductory guide to forensic hair examinations, the author details the characteristics observed between the different races and the different body areas. Also detailed in the guide is the basic structure of hair and the characteristics that are found useful when performing microscopical hair comparisons.

Deadman, H. A. (1985). Human hair comparisons based on microscopic characteristics. ***Proceedings of the International Symposium on Forensic Hair Comparisons,*** **45-49.**

De Forest, P. R., Gaensslen, R. E., Lee, H. C. (1983). Forensic Science - An Introduction to Criminalistics: Chapter 8 Fibers and Hairs. New York: McGraw-Hill.

Oien, C. T. (2009). Forensic Hair Comparison: Background Information for Interpretation. *Forensic Science Communications*, 11, 2.

3. What literature addresses the transfer and persistence of hair evidence and any possible limitations of secondary and higher order transfers?

Pounds C. A., Smalldon, K. W. (1975). The Transfer of Fibres Between Clothing Materials During Simulated Contacts and their Persistence During Wear: Part I – Fibre Transference. *Journal of Forensic Science Society*, 15, 17-27.

The authors of this paper performed research on the effects of pressure, type of recipient garment, number of repeated contact passes and fiber length on the transfer of wool fibers. The findings indicated that more fibers would transfer with greater pressure and decrease with each consecutive pass. It also showed that shorter fibers were transferred in great numbers during high pressure contact and that the fibers transferring did not vary significantly based on the transferring garment. Since wool fibers are a form of animal hair from sheep, it is then expanded out that human hairs would react in a similar fashion. This idea is confirmed in several subsequent studies done by the authors specifically on human hairs.

Pounds C. A., Smalldon, K. W. (1975). The Transfer of Fibres Between Clothing Materials During Simulated Contacts and their Persistence During Wear: Part II – Fibre Persistence. *Journal of Forensic Science Society*, 15, 29-37.

In continuing their research, the authors began to look at how long the fibers would persist based on the type of recipient garment and transferring material. To do this, fibers were transferred to the recipient garment and counted. The garment was then worn and at different time intervals, the transferred fibers were counted again. The final conclusion of this article was that fibers persist for short periods of time with 18% of the wool fibers remaining after 4 hours and 3% of the fibers remaining after 34 hours.

Dachs, J., McNaught, I. J., Robertson, J. (2003). The Persistence of Human Scalp Hair on Clothing Fabrics. *Forensic Science International*, 138, 27-36.

The authors of this paper researched the persistence of human hairs after they have been transferred to different types of recipient garments. The findings of this study correlate with the Pounds and Smalldon studies on wool fiber transfer. In this study most of the hairs were lost within the first 4 hours. Only when the recipient garment was made of wool did the hairs persist longer. By 8 hours all of the hairs were lost on all the garments except for the rough wool recipient garment where 20% of the hairs persisted.

Gaudette, B. D. and Tessarolo, A. A. (1987). Secondary Transfer of Human Scalp Hair. *Journal of Forensic Sciences,* 32, 1241-1253.

In a series of experiments the authors attempt to determine the evidentiary significance of possible secondary transfer of human head hairs. The results of these experiments showed that finding secondarily transferred hairs is reasonably common. Based on the experiments, factors were postulated as to why secondary transfers are more likely or less likely. Secondary transfers are more likely when horizontal surfaces are involved, when the suspects and/or victim are wearing rough textured or wool clothing, when unclean individuals with poor grooming habits are involved, when objects have been used by several people, and when an individual has many personal contacts before the crime. Some factors that make deposition of hairs on objects by secondary transfer less likely are when a large number of hairs associated to a single individual have been recovered from an item, when there is two way transfer, when the suspect and/or victim are wearing smooth textured clothing, when the suspect and/or victim are wearing tight fitting clothing, and when the suspect and/or victim are wearing clothing that is neat and clean.

Exline, D. L., Smith, F. P., Drexler, B. S. (1998). Frequency of Pubic Hair Transfer During Sexual Intercourse. *Journal of Forensic Sciences,* 43, 505-508.

Evett, I. W. (1990). The Theory of Interpreting Scientific Transfer Evidence. *Forensic Science Progress,* 4, 143-179.

Keating, S. M. (1982). The Cross Transference of Pubic Hairs During Sexual Intercourse. *Metropolitan Police Forensic Science Laboratory Report 23*.

Mann, M. (1990). Hair Transfers in Sexual Assault: a 6-year Case Study. *Journal of Forensic Sciences,* 35, 951-955.

Peabody, A. J., Thomas, K., Stockdale, R. (1985). On the Nature of Human Head Hairs Shed on to Various Types of Headgear. *Proceedings from the 10th International Association Forensic Science, Oxford 1984*.

Pounds C. A., Smalldon, K. W. (1975). The Transfer of Fibres Between Clothing Materials During Simulated Contacts and their Persistence During Wear: Part III – A Preliminary Investigation of the Mechanisms Involved. *Journal of Forensic Science Society,* 15, 197-207.

Quill, J. L. (1985). The Transfer Theory of Hairs Applied to the Normal Work Day. *Proceedings International Symposium on Forensic Hair Comparisons.*

Robertson, J., Harding, H., Somerset, H. (1987). The Persistence of Hairs on Clothing. *Canadian Society Forensic Science Journal,* 20, 240.

Simons, A. A. (1986). Hair Evidence on Laundered Items. *Crime Laboratory Digest,* 13, 78-81.

Stone, I. C. (1984). Hair and its Probative Value as Evidence. *Texas Bar Journal,* March, 275-279.

4. What literature addresses the evaluation of the context of evidentiary hairs as found and their significance in associations (e.g. hairs recovered from heavily traveled/soiled areas vs. hairs found on a victim's body or clothing)? Does the location of the hair evidence (public locations vs. body or garments) influence source inference?

   Fallon, T. C., Stone, I. C., Petty, C. S. (1985). Hair on victim's hands: value of examination. *Proceedings of the International Symposium on Forensic Hair Comparisons,* 145.

   The author looked at 400 cases where fingernail clippings or loose hairs from the victim's hands were submitted. 53 of these cases contained head hairs. In 9 of these cases the head hairs were identified as being different than the victims' own hair samples. In 44 of the cases the head hairs were consistent with the victims' own head hair samples. Body hairs were found in 31 of the cases; however no comparisons were performed between these hairs. In 2 of the cases, pubic hairs were found which were consistent with the victims' own pubic hair samples.

   Gaudette, B. D. and Tessarolo, A. A. (1987). Secondary Transfer of Human Scalp Hair. *Journal of Forensic Sciences,* 32, 1241-1253.

   See question 3.

5. What literature addresses the reliability of using the various physical features of hair for assessing race and source location (e.g. head, pubic, etc.), and the range of characteristics that may be encountered when making such determinations?

   Hooton, E. A. (1931). Up from the Ape. New York.

   In this book, the author has a section that covers hair. The author categorizes the distinctions between the Mongoloid, Negroid and European racial groups. The general theme of the book is the evolution of man from ape.

   Trotter, M. (1938). Anthropometry: A Review of the Classification of Hair. *American Journal of Physical Anthropology,* 24, 105-126.

   The author of this article reviews anthropological papers from different scientists around the world who have attempted to classify hairs from as early as 1825. Some of the articles reviewed focused on race determination. The author's conclusion based on this review of articles was that the general macroscopic characteristics of head hairs are of better use than the classifications based on microscopic characteristics.

Steggerda, M., Seibert, H. C. (1941). Size and Shape of Head Hair from Six Racial Groups. *The Journal of Heredity,* 32, 315-318.

The authors compared hairs collected from the Dutch whites; hairs from three Native American tribes: the Hopi, the Navajo and the Zuni; Negroid hairs from men at the Tuskegee Institute; and Mayan hair. The study demonstrated the variation in size and shape in human head hair. It was found in general that the Maya have the roundest hair and the Negroid hairs are the most elliptical; the Hopi the coarsest hair and the Dutch the finest hair. The authors concluded the cross sectional hair dimensions indicate Indian, Dutch and Negroid hairs fall into three separate categories.

Hicks, J. W. (1977). Microscopy of Hairs: A Practical Guide and Manual. Issue 2. Washington, DC: Federal Bureau of Investigation.

Deedrick, D., Koch, S. L. (2004). Microscopy of Hair Part 1: A Practical Guide and Manual for Human Hairs. Quantico, VA: Federal Bureau of Investigation.

In an introductory guide to forensic hair examinations, the authors detail the characteristics observed between the different races and the different body areas. Also detailed in the guide is the basic structure of hair and the characteristics that are found useful when performing microscopical hair comparisons.

Bisbing R. E. (2002). Forensic Science Handbook Volume 1 2nd Edition: Chapter 7 – The Forensic Identification and Association of Human Hair. Edited by Saferstein, R., New Jersey: Prentice-Hall Inc.

See question 2

Garn, S. M. (1951). Types and distribution of the hair in man. *Annals of the New York Academy of Science,* 53, 498-507.

Pinkus, F. (1927). Die Normale Anatomie der Haut. Handbuch der Haut- und Geschlechtskrankheiten. Berlin: Springer.

Thohzur et al (2006). Structural characteristics and mechanical behavior of beard hair. Journal of Materials Science, 41(4), 1109-1121.

Tolgysesi et al (1983). A comparative study of beard and scalp hair. Journal of the Society of Cosmetic Chemistry, 34, 361-382.

Vernall, D. G. (1963). A Study of the Density of Pigment Granules in Hair from Four Races of Men. *American Journal of Physical Anthropology,* 21, 489-496.

Vernal, D. G. (1961). A Study of the Size and Shape of Cross Sections of Hair from Four Races of Men. *American Journal of Physical Anthropology,* 19, 345-350.

6. What is the literature describing the potential links between taxonomy/pattern recognition and the hair comparison process?

   Oien, C. T. (2009). Forensic Hair Comparison: Background Information for Interpretation. *Forensic Science Communications*, 11, 2.

   The author of this article reviewed the basis for microscopical hair analysis and comparison. In this article, taxonomy is referenced as a basis of the idea of hair analysis and comparison. The author refers to the use of classifying biodiversity and how this applies to categorizing different races, body areas, color and phase of growth.

   Robertson, J. (1999). Forensic Examination of Hairs. Chapter 7. London: Taylor and Francis.

7. What literature describes the various qualitative observations and measurements that are made during hair analysis?

   Ogle, R.R. and Fox, M.J. (1999). Atlas of Human Hair: Microscopic Characteristics. Boca Raton: CRC Press.

   This text provides photographic archetypes for the microscopic characteristics of human hair and the variates of the characteristics seen in forensic examinations, including curl; color; pigment distribution and density; cortical fusi; and ovoid bodies. The illustrations provide a uniform basis for describing the characteristics and their variations for forensic professionals in differing geographical areas. The documentation of hair characteristics using the scoring system outlined in this atlas allows researchers to develop data regarding the frequency of characteristics within the hairs of one or more individuals and the assessment of whether certain hair characteristics are co-dependent.

   Bisbing R. E. (2002). Forensic Science Handbook, Volume 1, Second Edition: Chapter 7 – The Forensic Identification and Association of Human Hair. Edited by Saferstein, R., New Jersey: Prentice-Hall Inc.

   Bisbing, R. (1985). Human Hair in a Forensic Perspective. *Proceedings of the International Symposium on Forensic Hair Comparisons*, 35-44.

   Deedrick, D., Koch, S. L. (2004). Microscopy of Hair Part 1: A Practical Guide and Manual for Human Hairs. Quantico, VA: Federal Bureau of Investigation.

   De Forest, P. R., Gaensslen, R. E., Lee, H. C. (1983). Forensic Science - An Introduction to Criminalistics: Chapter 8 Fibers and Hairs. New York: McGraw-Hill.

Gaudette, B. D., Keeping, E. S. (1974). An attempt at determining probabilities in human scalp hair comparisons. ***Journal of Forensic Sciences,*** **19, 599-606.**

Gaudette, B. D. (1976). Probabilities and Human Pubic Hair Comparisons. ***Journal of Forensic Science,*** **21, 514-517.**

Hicks, J. W. (1977). Microscopy of Hairs: A Practical Guide and Manual. Issue 2. Washington, DC: Federal Bureau of Investigation.

Oien, C. T. (2009). Forensic Hair Comparison: Background Information for Interpretation. ***Forensic Science Communication,*** **11, 2.**

Robertson, J. (1999). Forensic Examination of Hairs. London: Taylor and Francis.

Sato, H (2002). Statistical evaluation of morphological data of Japanese head hair and the screening of evidential hair samples by cluster analysis. ***Legal Medicine*** **(4), 90-102.**

Strauss, M.T. (1983). Forensic characterization of human hair. ***The Microscope,*** **31, 15-29.**

Wickenheiser, R. A., Hepworth, D. G. (1990). Further evaluation of probabilities in human scalp hair comparisons. ***Journal of Forensic Sciences,*** **35, 1323-1329.**

a. Are distributions of these measurements recorded and compared within and between known and evidentiary populations?
b. Are these measurement distributions compared to general population statistics?
c. Is there any literature that investigates the possibility of automating this process?

The articles listed below are attempts to automate the hair comparison process.

Verma, M.S., Pratt, L. et al. (2002). Hair-MAP: A prototype automated system for forensic hair comparison and analysis, ***Forensic Science International,*** **129, 168-186.**

Hair samples from nine individuals (25 hairs from each individual) were imaged and used to construct an automated hair comparison program capable of comparing hair samples using five morphological characteristics and multivariate statistics. The program was accurate 83% of the time in determining whether or not two hair samples came from the same person.

Brooks. E., Comber, B., McNaught I., Robertson, J. (2011) Digital imaging and image analysis applied to numerical applications in forensic hair examination, ***Science and Justice,*** **51, 28-37.**

Telogen head hairs were collected from ten Caucasian individuals and compared using numerical measurements of color and pigment patterns. Using canonical plots from discriminant analysis, 3 of the hair samples were relatively separated from the remaining. The most successful technique was achieved using pair-wise analysis of the CIE XYZ color model, where the hair samples were separated from each other 88.9% of the time.

8. What literature describes any non-microscopic analyses (beyond DNA) of hair (e.g. spectrophotometry for color comparisons)?

Cornelis, R. (1972). Is it possible to identify individuals by neutron activation analysis of hair. ***Medical Science Law,*** **12, 188-194.**

Using neutron activation analysis, the author in this study tested hairs collected from an individual at one time as well as hairs collected from two individuals over 25 and 26 year time periods. The elements tested for were zinc, copper, gold, mercury, arsenic, antimony and manganese. The conclusion reached was that no element, excluding zinc, remained constant over the time periods tested. It was also concluded that the dispersion of zinc over the entire population is narrow and lacks specificity. The testing method was also destructive and precluded any future testing.

Ishizawa, F., Misawa, S. (1990). Capillary column pyrolysis-gas chromatography of hair: a short study in personal identification. ***Journal of the Forensic Science Society,*** **30, 201-209.**

The authors collected head hairs from 18 individuals. These hairs were subjected to Pyrolysis-gas chromatography (PyGC) and the pyrograms were analyzed. Some of the hairs were also subjected to GC-MS. Most of the elements observed were shown to be the same between individuals. Benzene, toluene and styrene differed among the donors but other donors may share the same observed values. By performing a blind trial, the authors concluded that the method may not be capable of yielding conclusive forensic evidence.

Obrusnik, I., Gislason, J., Maes, D., et al. (1972). The variation of trace element concentration in single human head hairs. ***Journal of Forensic Sciences,*** **17, 426-439.**

The authors of this study examined the variation of trace elements in single hairs using neutron activation analysis. The general result of this study was that the variation of the trace elements within a single hair shows a range of distribution similar to what was seen in the general population in previous studies.

Nagra, M. S., Pallah, B. S., Sahota, G. P. S., et al. (1992). A study of trace elements in scalp hair and fingernails of industrial workers of Ontario, Canada. ***Journal of Radioanalytical and Nuclear Chemistry,*** **162, 283-288.**

The authors in this study also used neutron activation analysis to study the trace elements in scalp hair and fingernails. In the scalp hair portion of this study, the findings showed that the environmental factors the workers were subjected to can be recognized in the hairs. However no significant differences in the distribution of the elements between the people can be observed.

Barret, J.A., Siegel, J.A., and Goodpaster J.V. (2010). Forensic discrimination of dyed hair color: I. UV-Visible microspectrophotometry. ***Journal of Forensic Science*****, 55, 323-333.**

Barret, J.A., Siegel, J.A., and Goodpaster J.V. (2011). Forensic discrimination of dyed hair color: II. Multi-variate Statistical Analysis. ***Journal of Forensic Science*****, 56, 95-101.**

Benner et al (2003). Characterization of surface organic components of human hair by on-line supercritical fluid extraction – GCMS: A feasibility study and comparison with human identification using mitochondrial DNA sequences. ***Journal of Forensic Science*****, 48(3), 554-563.**

Birngruber, C., Ramsthaler, F., Verhoff, M. A. (2009). The color(s) of human hair – forensic hair analysis with SpectraCube. ***Forensic Science International,*** **185, 19-23.**

Fraser et al (2007). Stable 2H isotope analysis of human hair and nails can aid forensic human identification. ***Rapid Commun. Mass Spectrum*****, 21, 3279.**

Gordus, A. (1973). Factors affecting the trace-metal content of human hair. ***Journal of Radioanalytical Chemistry,*** **15, 229-243.**

Jervis, R. E. (1966). The value of NAA hair comparisons in forensic investigations – a critique. ***Proceedings of the 1st International Conference on Forensic Activation.***

Lee, L. D., Ludwig, K., Baden, H. P. (1978). Matrix proteins of human hair as a tool for identification of individuals. ***Forensic Science,*** **11, 115-121.**

Miyake, B., Seta, S. (1990). Hair protein polymorphism and its application to forensic science hair comparison. ***Forensic Sci Rev,*** **2, 25-36.**

Pillay, K. K. S., Kuis, R. L. (1978). The potential and limitations of using neutron activation analysis data on human hair as a forensic evidence. ***Journal of Radioanalytical Chemistry,*** **43, 461-478.**

Robertson, J. (1999). Forensic Examination of Hair. London: Taylor and Francis, Chapter 4.

Singh et al (2009). Forensic analysis of oxidative hair dyes from commercial dyes and dyed hair samples by thin layer chromatography. *Journal of Forensic Identification*, 59(2), 172-189.

Tanada et al (1999). Practical GCMS analysis of oxidation dye components in hair fiber as a forensic investigative procedure. Journal of Forensic Science, 44(2), 292-296.

Vaughn, M. R., van Oorschot, R. A. H., Baindur-Hudson, S. (2009). A comparison of hair colour measurement by digital image analysis with reflective spectophotometry. *Forensic Science International*, 183, 97-101.

Wilhelm, M., Ohnesgorge, F. K. (1990). Cadmium, copper, lead and zinc concentrations in human scalp and pubic hair. *The Science of the Total Environment*, 92, 199-206.

9. What literature explores the variability of characteristics for an individual or any specific population that support the use of only 25 known (or 50 - including plucked hairs) exemplar hairs based on the statistics of sampling from a known distribution? Was this number arrived at arbitrarily or with statistical support?

Gaudette, B. D., Keeping, E. S. (1974). An attempt at determining probabilities in human scalp hair comparisons. *Journal of Forensic Sciences*, 19, 599-606.

Gaudette and Keeping conducted head hair comparisons of 861 hairs from 100 individuals. Of these, 92 were Caucasian, 6 were Mongoloid, and 2 were Negroid. The authors determined 6 to 11 hairs from each known head hair sample best represented the range of microscopic characteristics observed. A total of 366,630 examinations were conducted in the first study. Of these examinations, 9 pairs of hairs from different individuals were found to be indistinguishable. Gaudette et al used a card coding system of hair characteristics to assist with the comparisons. The authors found it difficult to reproduce the description of microscopic characteristics between different examiners. The authors also calculated a probability estimate for head hair comparisons that should not be applied to the entire population.

Gaudette, B. D. (1976). Probabilities and Human Pubic Hair Comparisons. *Journal of Forensic Science*, 21, 514-517.

In a similar paper, Gaudette used the same method as his first study and applied it to pubic hairs. Approximately 30 pulled hairs were obtained from 60 individuals of which all were Caucasian. Of these, six to eleven were selected to represent the range of microscopic characteristics in each pubic hair sample. A total of 101,368 comparisons were conducted. Of these examinations, 16 pairs of hairs from different individuals were found to be similar. As with the previous study with head hair samples, a card coding system of hair characteristics was used to assist with the comparisons. The authors also

calculated a probability estimate for pubic hair comparisons that should not be applied to the entire population.

Strauss, M.T. (1983). Forensic characterization of human hair. *The Microscope,* 31, 15-29.

A study was conducted comparing the microscopic characteristics of 100 individuals. Of these, 54 were Caucasian, 27 Mongoloid, and 17 Negroid. Seven hairs were chosen from each hair sample to represent the variation in microscopic characteristics. These hairs were mounted and labeled as the known hair samples. One additional hair was chosen from each of the hair samples and labeled as questioned hairs. Seven experiments were conducted comparing single question hairs to the designated known hair samples. All questioned hairs were correctly associated to their known source. In addition, all questioned hair samples were characterized into their correct racial groups. A checklist of hair characteristics was used to characterize all 800 hairs used in the study.

Wickenheiser, R. A., Hepworth, D. G. (1990). Further evaluation of probabilities in human scalp hair comparisons. *Journal of Forensic Sciences,* 35, 1323-1329.

Using the model from Gaudette, Wickenheiser collected hair samples from 97 individuals. From these hair samples, 5 to 13 dissimilar hairs were chosen from each known sample to represent the range of microscopic characteristics. An independent party set up a test using these hairs and an additional 53 hairs chosen at random. Two examiners conducted the same examinations with the assistance of a database to catalog the microscopic characteristics. Neither examiner found any hairs from different individuals which coincidentally matched.

10. What literature addresses any empirical studies looking at the degree of variation within and between individuals? If 10, 100, or 500 hairs are taken from an individual's head, how much variation is typical? Even if it can't be quantified, what would a 'checklist' or descriptive approach show?

Strauss, M.T. (1983). Forensic characterization of human hair. *The Microscope,* 31, 15-29.

See question 9

Gaudette, B. D., Keeping, E. S. (1974). An attempt at determining probabilities in human scalp hair comparisons. *Journal of Forensic Sciences,* 19, 599-606.

See question 9

Wickenheiser, R. A., Hepworth, D. G. (1990). Further evaluation of probabilities in human scalp hair comparisons. *Journal of Forensic Sciences,* 35, 1323-1329.

See question 9

11. What literature exists that has looked at developing "coding" for critical categories like color or range of width? Have there been studies of test-retest reliability within examiners and across examiners as is standard for other types of tissue pathology (e.g. tumor stage and grade)?

    Gaudette, B. D., Keeping, E. S. (1974). An attempt at determining probabilities in human scalp hair comparisons. *Journal of Forensic Sciences,* 19, 599-606.

    Podolak, A. P., Blythe, C. E. (1985). A study of the feasibility of establishing a computer data bank for hair characterization using standard descriptive criteria. *Proceedings of the International Symposium on Forensic Hair Comparisons,* 149.

    In this study, five hairs were categorized by nine examiners using a predetermined multiple choice check list. For each hair, each examiner described the hairs differently. In addition, eight weeks after the initial survey, the hairs were reexamined by the same nine examiners. The examiners again described the hairs differently. To add, the examiner's descriptions were also dissimilar to their original examination.

    Wickenheiser, R. A., Hepworth, D. G. (1990). Further evaluation of probabilities in human scalp hair comparisons. *Journal of Forensic Sciences,* 35, 1323-1329.

    See question 9. In addition, the two examiners in the study used a computer database system to categorize the hairs to assist in making the comparisons. It was noted in the study that the two examiners described the hairs differently when making the initial examination of the microscopic characteristics.

    - We are not aware of research into test/retest reliability within examiners since it is difficult to perform such a test. If you were to give a person sets of hairs to compare and then a short time later give them the same hairs, they will remember what they examined and compared and may be biased towards reaching the same conclusion. As far as between different examiners, since 2009 a company called Forensic Testing Services has been administering hair comparison proficiency tests. These tests are sent to many examiners using the same source across the tests for each sample. A high percentage of the examiners taking these tests reach the same conclusion as to associations and non-associations.

12. What literature describes the occurrence/incidence rate of individual microscopic features?

    Many studies have used a checklist to categorize the microscopic characteristics found in hairs to assist in determining which hairs should be compared to each other. However, the purpose of these studies was not to describe the occurrence/incidence rate of these

features and the information was not reported. The following papers used such a checklist:

Gaudette, B. D., Keeping, E. S. (1974). An attempt at determining probabilities in human scalp hair comparisons. *Journal of Forensic Sciences,* 19, 599-606.

Gaudette, B. D. (1976). Probabilities and Human Pubic Hair Comparisons. *Journal of Forensic Science,* 21, 514-517.

Strauss, M. T. (1983). Forensic characterization of human hair. *The Microscope,* 31, 15-29.

Wickenheiser, R. A., Hepworth, D. G. (1990). Further evaluation of probabilities in human scalp hair comparisons. *Journal of Forensic Sciences,* 35, 1323-1329.

13. What literature is there for determining the threshold as well as the uncertainty in determining exclusions, inconclusive and consistent/similar?

Aitken, C. G. G., Robertson, J. (1986). The value of microscopic features in the examination of human head hairs: statistical analysis of questionnaire returns. *Journal of Forensic Sciences,* 31, 546-562.

Cwiklik, C. (1999). Evaluation of the significance of transfers of debris: criteria for association and exclusion. *Journal of Forensic Sciences,* 44, 1136-1150.

Gaudette, B. D. (1985). Strong negative conclusions in hair comparison – a rare event. *Journal of Forensic Sciences,* 17, 32-37.

The author of this paper describes situations that would either strengthen or diminish the value of associations. Some factors that strengthen a conclusion are two or more mutually dissimilar hairs found to be similar to a known sample, hairs with unusual characteristics, hairs found in unexpected places, and two way transfer. Some factors that weaken a hair association are the presence of incomplete hairs, questioned hairs which are common or featureless, hairs of non-Caucasian racial origin, a questioned hair found in conjunction with other unassociated hairs, and known samples with large intrasample variation. Some factors that weaken a non-association are deficiencies in the known sample, incomplete questioned hairs, and the questioned hair has macroscopic and microscopic characteristics close to those of the known sample. Some factors which tend to strengthen a non-association are the known sample has more than the recommended number of hairs, the known sample shows little intrasample variation, the questioned hair has macroscopic and microscopic characteristics very dissimilar to those of the known sample, and two or more hairs found together in a clump are dissimilar to the known sample. Some examples of very dissimilar hairs would be hairs of differing racial origin or the questioned hair is artificially treated and the known sample is not.

14. What is the literature that documents and describes the specificity of post-mortem root banding in deceased individuals and the biological/chemical factors involved in its formation?

    Possibilities of how post-mortem root banding occurs are discussed in some of the literature below. However, the mechanisms and factors involved in the formation of postmortem banding have not been determined.

    Petraco N, Fraas C, Callery FX, De Forest PR (1988). The morphology and evidential significance of human hair roots. *Journal of Forensic Sciences,* 33, 68-76.

    A portion of this paper discusses postmortem root banding and defines it as an opaque band approximately 0.5mm above the root bulb and approximately 2mm below the skin surface. The authors suggest the band is composed of elongated air spaces and has been observed in hairs from individuals deceased for as little as 8 hours. The authors also report the band appears in a particular zone due to the hair being more keratinized above the zone and the root being deeper in the skin and thus more protected below the zone.

    Linch, C. A., Prahlow, J. A. (2001). Postmortem microscopic changes observed at the human head hair proximal end. *Journal of Forensic Sciences,* 46, 15-20.

    The authors examined hair samples from 22 Dallas County Institute of Forensic Sciences cases where the time of death was documented by medical investigator reports. The root ends of these hairs were categorized into five categories which are no changes, distal root banding, proximal root banding, hard keratin point and brush like cortical fibrils. The findings were that most cases where the postmortem interval was greater than 4 days exhibited a mixture of postmortem hair root ends. There were also mixtures of putrid hairs with anagen hairs that showed no apparent changes. Of the 22 cases studied, there were a greater number of hard keratin point and brush like cortical fibrils than the banded root ends. The authors report postmortem root banding is typically observed in the shaft of the hair around the location of the sebaceous gland entering the hair follicle. The results also suggest the timing of these observed postmortem changes cannot likely be used to determine postmortem interval.

    Koch, S. L., Michaud, A. L., Mikell, C.E. (accepted to be published in January 2013). Taphonomy of Hair – A Study of Postmortem Root Banding. *Journal of Forensic Sciences.*

    The authors examined over 20,000 hairs collected from twenty-three human cadavers. The cadavers were placed at the University of Tennessee's Forensic Anthropology Center in various environmental conditions. Hair samples were collected daily from all areas of the scalps and examined microscopically. Hairs collected from cadavers immersed in water or placed in protected or climate controlled environments showed a delayed appearance of root banding. Hairs from cadavers stored in higher temperatures or in vehicles showed an increased rate of root banding. The authors noted postmortem

changes at the root end were only observed in hairs in the apparent anagen and catagen growth stages. The authors also conclude that no meaningful rate of putrefaction versus time and temperature could be calculated due to the many variables that effect the postmortem changes.

Scientific Working Group on Materials Analysis (2005). Forensic Human Hair Examination Guidelines. ***Forensic Science Communications,*** **7.**

Saferstein, R., Bisbing R. E. (2002). Forensic Science Handbook, Volume 1, Second Edition: Chapter 7 – The Forensic Identification and Association of Human Hair. New Jersey: Prentice-Hall Inc.

Tafaro, J. T. (2000). The use of microscopic postmortem changes in anagen hair roots to associate questioned hairs with known hairs and reconstruct events in two murder cases. ***Journal of Forensic Sciences,*** **45, 495-499.**

15. What is the literature on error rates for hair examinations? This includes any literature that quantifies the rate and significance of false positives and false negatives.

Gaudette, B. D., Keeping, E. S. (1974). An attempt at determining probabilities in human scalp hair comparisons. ***Journal of Forensic Sciences,*** **19, 599-606.**

Gaudette, B. D. (1976). Probabilities and Human Pubic Hair Comparisons. ***Journal of Forensic Science,*** **21, 514-517.**

Kolowski et al (2004). A comparison study of hair examination methodologies. ***Journal of Forensic Science,*** **49, 1253-1255.**

Smith, S. L., Linch, C. A. (1999). A review of major factors contributing to errors in human hair associations by microscopy. ***American Journal of Forensic Medicine and Pathology,*** **20, 269-273.**

Strauss, M. T. (1983). Forensic characterization of human hair. ***The Microscope,*** **31, 15-29.**

Wickenheiser, R. A., Hepworth, D. G. (1990). Further evaluation of probabilities in human scalp hair comparisons. ***Journal of Forensic Sciences,*** **35, 1323-1329.**

16. What is the literature on cognitive bias and its effects on the hair examination process?

Budowle B. et al (2009). A perspective on errors, bias, and interpretations in the forensic sciences and direction for continuing advancement. ***Journal of Forensic Sciences,*** **54, 798-809.**

17. What literature/studies address the selection process of finding suitable hairs for comparison? Can an improper selection process bias the examination by potentially only looking at a few outliers that are macroscopically like the exemplars?

Hicks, J. W. (1977). Microscopy of Hairs: A Practical Guide and Manual. Issue 2. Washington, DC: Federal Bureau of Investigation.

Deedrick, D., Koch, S. L. (2004). Microscopy of Hair Part 1: A Practical Guide and Manual for Human Hairs. Quantico, VA: Federal Bureau of Investigation.

Gaudette, B. D. (1985). Strong negative conclusions in hair comparison – a rare event. *Journal of Forensic Sciences,* 17, 32-37.

Robertson, J. (1999). Forensic Examination of Hairs. London: Taylor and Francis.

Saferstein, R., Bisbing R. E. (2002). Forensic Science Handbook Volume 1 2nd Edition: Chapter 5 – The Forensic Identification and Association of Human Hair. New Jersey: Prentice-Hall Inc.

De Forest, P. R., Gaensslen, R. E., Lee, H. C. (1983). Forensic Science - An Introduction to Criminalistics: Chapter 8 Fibers and Hairs. New York: McGraw-Hill.

Oien, C. T. (2009). Forensic Hair Comparison: Background Information for Interpretation. *Forensic Science Communication,* 11, 2.

- Hair comparisons should be performed between the same somatic regions (head hairs to head hairs; pubic hairs to pubic hairs; facial hairs to facial hairs). Head hairs, pubic hairs and facial hairs are the most easily identified by their characteristics and provide the most meaningful microscopical comparisons. The other body areas do not contain sufficient variation between individuals to conduct meaningful microscopic comparisons.

- There is no specific length criterion for which a hair is determined to be suitable for comparison so that a meaningful conclusion can be reached. There may be more comparative value for a hair that is 1/8" long than a hair that is ½" long. Suitability for microscopical comparisons is dependent on the characteristics of the hair in question.

- Each questioned hair comparison is its own exam. One would not group all the hairs on an item of evidence and determine that since one hair on that item is macroscopically like the exemplar that all the hairs on that item must be like the exemplar.

- An inadequate or improperly collected known hair sample (s) can result in false exclusions.

18. What literature/studies are there regarding inter-laboratory collaborations to determine how much agreement/disagreement exists between associations made by different individuals working under different conditions?

Forensic Testing Services reports for proficiency tests

Since 2008 a company called Forensic Testing Services has been administering hair comparison proficiency tests. These tests are sent to many examiners using the same source across the tests for each sample. A high percentage of the examiners taking these tests reach the same conclusion as to associations and non-associations. Here are the results reported since 2008:

2008:
19 of 20 respondents agreed with the manufacturer's results in regards to an association between item #1 and item #2, with one inconclusive result
20 of 20 respondents agreed with the manufacturer's results in regards to eliminating item #3 as the source of item #1

2009:
43 of 45 respondents agreed with manufacturer's results in regards to an association between item #1 and item #3, with one respondent incorrectly excluding item #3 and another respondent reaching an inconclusive result
44 of 45 respondents agreed with the manufacturer's results in regards to excluding item #2 as being the source of item #1, with one inconclusive result.

2010:
54 of 54 respondents correctly associated item #3 as being a possible source of item #1 and correctly excluded item #2 as being a possible source of item #1

2011:
51 of 51 respondents correctly associated item #3 as being a possible source of item #1 and correctly excluded item #2 as being a possible source of item #1

Peterson, J. L., Markham, P. (1995). Crime laboratory proficiency testing results, 1978-1991, II: resolving questions of common origin. ***Journal of Forensic Sciences,*** **40, 1009-1029.**

The authors looked at proficiency test results for several forensic disciplines, including hair examinations. The results of five proficiency tests are analyzed with results and reasons for the possible wrong answers, the most common being insufficient known samples. The results are based on a total of comparisons with correct associations as well as correct non-associations. In total, laboratories reported associations and non-associations that agreed with the manufacturers results in 74% of the cases, disagreed in 8% of the cases and had inconclusive results in 18% of the cases.

19. What literature addresses how environmental conditions (e.g. diet, sun exposure, chemical exposure, hair treatments), disease, and aging influence variability in hair characteristics over time? What is the literature describing and documenting such changes? What studies have been performed to document the effect such changes have on the hair comparison process?

Prokopec, M., Glosová, L., Ubelaker, D. H. (2000). Change in hair pigmentation in children from birth to 5 years in a central European population (longitudinal study). *Forensic Science Communications,* 2, number 3.

Hairs were collected from 232 healthy children (114 boys and 118 girls) over a 5 year period. The hair colors were compared with 24 shades of the Fischer and Saller color standards. The results of this study demonstrated how hair color changes over time with children, sometimes starting very dark, then lightening in color until darkening again. It is believed that the dark hair at birth is due to hormonal factors from the mother.

Steggerda, M. (1941). Change in hair color with age. *Journal of Heredity,* 32, 402-403.

The author researched changes in hair color of 220 males and 194 females ranging in age from 6 to 18. Hairs from these individuals were examined annually over a 10 year period in the month of November. All of the children were of Dutch heritage. The color of the hair was compared to the Fischer-Saller Haarfarbentafal color chart. The general result of the study demonstrated how hair in children 6 to 18 becomes darker over time.

Trüeb, R. M., Tobin, D. J. (2010). Aging Hair. Heidelberg: Springer.

This book goes over many of the factors that can change in a hair as a human ages from birth to death and after. Some of the topics discussed are hair loss, the aging of hair pigmentary unit, the effect of UV radiation on scalp and hair growth, hair photoaging, the effect of tobacco smoking on hair, hair transplantation and many other topics involving attempts at reversing the aging process of hairs.

Camacho, F. M., Randall, V. A., Price, V. H. (2011). Hair and its Disorders: Biology, Pathology and Management. New York: Informa Healthcare.

This book covers the biology of the hair and the normal growth and life span of a hair. It also covers the conditions and diseases that affect the appearance of hairs and possible remedies to these problems.

Robbins, C. R. (1994). Chemical and Physical Behavior of Human Hair 3rd edition. New York: Springer-Verlag.

This book describes the morphological and chemical structure of human hair. It then goes on to describe different treatments that can be performed to human hairs (reducing

the hair for straightening or curling, bleaching, dyeing, etc.) and how these treatments affect the normal characteristics.

Chang, B. S., Hong, W. S., Lee, E., et al. (2005). Ultramicroscopic observations on morphological changes in hair during 25 years of weathering. ***Forensic Science International,*** **151, 193-200.**

The authors looked at the changes in characteristics of hairs from deceased individuals in differing conditions. It was found that after 5 years, no significant changes in morphology were observed. After 15 years losses in various layers of the hair were found. After 25 years the hair shafts showed pores extending to the medulla.

Trotter, M., Duggins, O. H. (1948). Age changes in head hair from birth to maturity. I. Index and size of hair of children. ***American Journal of Physical Anthropology,*** **6, 489-506.**

Wynkoop, E. M. (1929). A study of age correlations of the cuticular scales, medullas, and shaft diameters of human head hair. ***American Journal of Physical Anthropology,*** **13, 177-188.**

20. What literature addresses studies that have been performed to determine the range of differences observed between the hairs of closely related individuals/groups such as twins, family, communities and broad racial/ethnic groups? This includes detailing which hair characteristics are considered "frequent" or "rare" among populations, and of those characteristics, which are considered "different" to the point of concluding with certainty that hairs are not from the same source.

Bisbing, R. E., Wolner, M. F. (1984). Microscopical Discrimination of Twins' Head Hair. ***Journal of Forensic Sciences,*** **29, 780-786.**

Duplicate head hair samples from 17 pairs of twins and one set of triplets were compared in a blind study. Each hair sample was separated into two mounted slides, each containing 25 hairs. Using macroscopic and microscopic characteristics of the head hairs, the researchers were able to correctly associate the specimens with the duplicate sample and never with a twin. In a second part of the study, simulated forensic comparisons were performed. Seven tests were prepared where one questioned hair was compared to several randomly selected known samples. In this part of the study none of the known pools randomly selected actually contained the corresponding known sample from the questioned hair. In the seven tests, the first examiner correctly excluded 47 out of 52 samples and the second examiner correctly excluded 49 out of 52 samples.

*It should be noted that throughout this study, the hairs were mounted only between two glass microscope slides. In a full microscopical analysis, the hairs would be mounted in a mounting media which allows for greater recognition of internal detail and resolution of the microscopic characteristics.

Lamb, P. and Tucker, L.G. (1994). A study of the probative value of Afro-Caribbean hair comparisons. *Journal of the Forensic Science Society*, 34, 177-179.

The authors reported on a series of sexual assaults in which several pubic hairs were recovered. Known hair samples were collected from 118 Afro-Caribbean individuals for comparison to these question hairs. Of the 118 individuals, 62% were excluded using low power magnification. Another 25% were excluded using higher magnification resulting in 107 out of the 118 Afro-Caribbean individuals being excluded as donors of the question hairs.