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Contact Lens Burial Simulation Study

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Abstract

Contact lenses have rarely been relevant in criminal investigations and/or trials. Furthermore, there are no established protocols for the forensic evaluation of contact lenses in a criminal case. Recently, an article concerning the forensic use of contact lenses in a murder case was published in the Journal of Forensic Science. After obtaining a court order, the body of murder victim Janet Abaroa was exhumed for further forensic evaluation. Contact lens remnants were retrieved from her orbital contents and became key material evidence in her murder trial.

This paper describes the contact lens burial simulation study, which served as a vital part of the Abaroa forensic investigation. Additionally, a retrospective summary of other criminal cases involving contact lenses is presented. A finalized protocol for the forensic analysis of contact lenses in a criminal case is presented to assist future investigators.

Keywords: Forensic science; Forensic ophthalmology; Burial simulation; Contact lenses; Exhumation; Murder; Abaroa; Inversion marks

Introduction

The idea of creating a contact lens for the human eye was first proposed by Leonardo Da Vinci in 1508. In his *Manual D, Codex of the Eye*, Da Vinci describes a method that would alter the refractive power of the cornea by submerging the eye in a bowl of water to change the refractive properties of light (Figures 1 and 2). Over the centuries, there have been major developments in contact lens production and dissemination throughout the world. Currently, in the United States, there are approximately 36 million [1-3] people who wear soft contact lenses. Modern standards of care dictate that the prescribing doctor maintains electronic medical records (EMR) of the dispensed Rx for contact lenses. The following criminal cases represent the various uses of contact lenses as important forensic evidence.

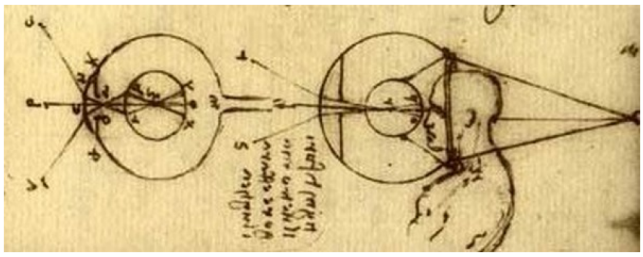

Figure 1: Da Vinci Contact Lens Diagram from his Manual D. Codex.

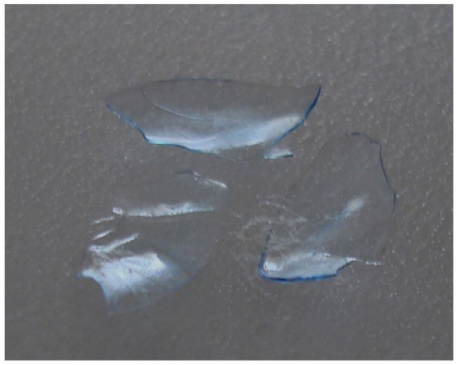

Figure 2: Acuvue 2 contact lens fractured into fragments after dehydration.

Synopsis of Murders Involving Contact Lenses as Key Forensic Evidence

In 1977, Linda Jill Velzy, an 18-year-old college co-ed, was murdered. Her frozen body was recovered, and its examination revealed a missing soft contact lens from her left eye. Based on an informant's tip, the police searched the car of Ricky A. Knapp, a known sex offender, and the brittle dried fragments of a soft contact lens were discovered. After reconstituting the fragments, the contact lens resumed its normal shape, and the manufacturer's inversion marks were identified. The intact soft contact lens from the victim's right eye and the restored fragments of the contact lens from the suspect's car were sent to the contact lens manufacturer. The optical company confirmed that the contacts were a match to the victim's optical prescription. The contact lens was a key piece of material evidence when used in coordination with the optical manufacturer and the dispensing eye doctor's prescription [4].

In the 1998 murder case of Randi Mebruer, Derrick Todd Lee, aka the "Baton Rouge Serial Killer", entered the house and brutally murdered Ms. Mebruer. The assailant struck the victim with enough force to dislodge the contact lenses from her eyes onto the carpet inches apart from each other. The contact lenses were considered vital material evidence in this case.

In 2007, Lloyd Rayney was convicted of killing his wife, Corryn Rayney. Phone tapping eventually led to his arrest and sentencing. Further investigation uncovered one contact lens in the backseat of Corryn's car. This important evidence, coupled with other salient evidence, led investigators to conclude that Corryn's body was in

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the car prior to the disposal of her body by her husband. The second contact lens was never recovered [5].

In the 2007 murder case of Katherine "Katy" Brown, her brother, Cody, was arrested and charged with premeditated murder on the basis of contact lens evidence that was found in Cody's car at the scene of the crime. The contact lens served as critical evidence in proving that Cody was at the scene of the murder and in naming him the true killer in this case. Crime scene investigators were able to match the contact lens left at the scene to Katy Brown's contact lens prescription.

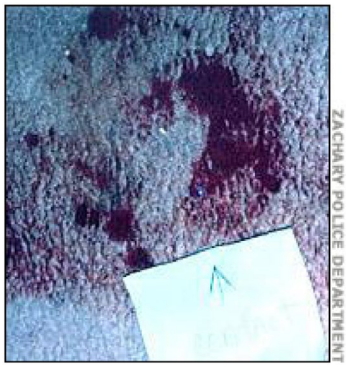

Figure 3: Mebruer's contact lenses left at the scene of the Mebruer murder. Zachary Police Department forensic files 1997.

Yoknapatawpha County Forensic Laboratory

DATE ANALYSIS PERFORMED: 6/29/2007 Madeline Holland, Ph.D. 555 Jackson Avenue Oxford, MS 38655 662-2XXXX (FAX 662-2XXXX)	**Analysis:** Defining Characteristics

SUMMARY REPORT OF CONTACT LENS ANALYSIS

Case Description: Katherine Irene Brown Homicide	**Case #** 000492-31A-2007
Investigative Agency: Yoknapatawpha County Sheriff's Department	**Investigating Officer(s):** Det. S. Murphy, Det. T. Armstrong

EVIDENCE ANALYZED

The following item was taken into evidence at the scene after being found on victim's body. The item was processed by the Yoknapatawpha County CSU division and the results are as follows:

Evidence Item: 000119-49 – Contact Lens	
Type	Non Colored Contact Lens with Blue Tint
Prescription	Base Curve: 8.8 Diameter: 14.0 Power: -1.25
Brand	Unknown

Figure 4: Forensic analysis of contact lens evidence found in suspect Cody Brown's vehicle. Yoknapatawpha County Forensic Laboratory.

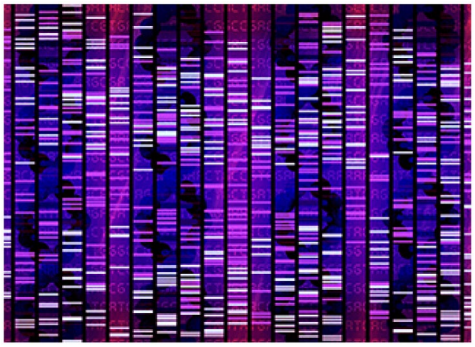

Figure 5: Sample of Polymerase Chain Reaction (PCR) creates copies of DNA used in Forensic Testing, Instituto de Biología, UNAM, Mexico City.

Figure 6: Sample A was the critical piece of evidence that convicted Raven Abaroa. Note inversion marks labeled 123, that identified the remnant as a Vistakon Acuvue 2® contact lens.

Figure 7: Contact lenses used in burial simulation.

When presented with this evidence, he fully confessed to the murder (Figures 3 and 4).

In another 2007 case, the bodies of Paula and Alijah O'Conner were found in their St. Petersburg, Florida, home. Ralph Wright, the father of Alijah and the ex-boyfriend of Paula, currently sits on death row for the murder of the two victims based on contact lens evidence that was found near the body and was used to recover DNA matching it to Paula O'Conner. In this case, PCR methods were used to recover "Touch DNA" from the contacts lenses and match them to the victim (Figure 5) [6].

In 2010, contact lens remnants were retrieved from the exhumed body of the murder victim Janet Abaroa. This pivotal piece of evidence refuted the story that her husband, Raven Abaroa, told the police. He said that Janet had gone to bed wearing glasses the night she was murdered. When taking inventory of the victim's possessions, detectives noted that Janet's contact lenses were not in their contact lens case. After obtaining a court order, her body was exhumed five years post-burial, and contact lens remnants were identified, which contradicted her husband's testimony. To provide a scientific explanation for the change in the appearance of the contact lens remnants, a burial simulation study was performed to reproduce the yellow discoloration patterns noted on the material evidence of Sample A (Figure 6).

Materials and Methods

Following standard American funeral protocols [7], three pairs of enucleated pig eyes with applied soft contact lenses were embalmed and buried in caskets. The pig eyes were obtained from a local swine processing plant after the animals had been euthanized under

veterinary supervision. The pig eyes were stored in a refrigeration unit until the study was to be performed. The simulation was performed to determine the effects of the environment and post-mortem ocular bio-degeneration on the physical properties of the soft contact lenses. This empirical evidence was needed to corroborate the appearance of the Acuvue 2® soft contact lens remnants retrieved in the Abaroa murder.

The following materials were used in this study: 6 enucleated pig eyes, 4 varieties of soft contact lenses, blunt-tipped microsurgical forceps, gauze oval eye pads, 3 small wooden caskets, burial linen, lens caps, Opti Free contact lens wetting solution, "Dodge Dis Spray", a centimeter ruler, string, cement slabs, bricks, shovel, 3 signs, and a Sony Cybershot digital camera.

Four of the most popular types of soft contact lenses were used: Vistakon Acuvue 2® lenses, Alcon Air Optix® lenses, Cooper Vision Proclear® lenses, and Cooper Vision Biofinity® Toric lenses. The Acuvue 2® lenses served as the controlled variable in this experiment. The Air Optix®, Proclear®, and Biofinity® lenses served as additional variables to be tested (Figure 7).

First, the pig eyes were removed from the refrigerator and grouped into pairs. Acuvue 2® contact lenses were placed onto three of the pig eyes with blunt-tipped microsurgical forceps (Figure 8). The first set of pig eyes contained one Acuvue 2® lens, (-2.25) 8.7, 14.0 (right eye) and one Air Optix® lens, (-2.50) 8.4, 13.8 (left eye).

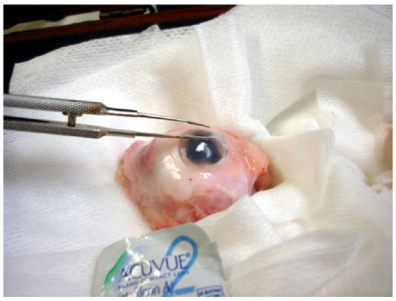

Figure 8: Acuvue 2 contact lens being placed on an enucleated pig eye using blunt-tipped microsurgical forceps.

Figure 9: Vault containing the wooden caskets.

Figure 10: Blue stain on the Air Optix lens cover at the six month exhumation.

Figure 11: Close-up of Air Optix exhumed lens with stained lens cap.

Table 1: Results of the Contact Lens Burial Studies.

Contact Lens Type	Exhumation in Months	Yellow Deposits within Contacts (%)	Contact Lens Decomposition (%)	Loss of Contact Lens Tint (%)
Acuvue 2	6	10%	20%	N/A
Air Optix	6	5%	10%	100%
Acuvue 2	12	30%	20%	N/A
Proclear	12	35%	20%	100%
Acuvue 2	24	50%	35%	N/A
Biofinity Toric	24	35%	25%	100%

The pig eyes and contact lenses were then exposed to "Dodge Dis Spray", which is a chemical to slow the biodegradation process, as per standard funeral protocol in the state of North Carolina [7]. Plastic lens caps were placed over the pig eyes with the contact lenses. A second set of pig eyes was prepared in the same manner containing an Acuvue 2® (-2.25) 8.7, 14.0 (right eye) and a Proclear (-11.00) 8.5, 14.0 (left eye).

The third set of pig eyes was prepared in the same method as the previous two sets. They contained an Acuvue 2® (-2.25) 8.7, 14.0 (right eye) and a Biofinity® Toric (-1.50 -1.25 × 180) 8.7, 14.5 (left eye). The three treated sets of pig eyes with contact lenses were placed in miniature wooden caskets that measured 22.5 cm in length, 12.5 cm in height, and 14.5 cm in depth.

Next, the eyes with the contacts were covered with oval eye pads and funeral quality burial linen, and the caskets were sealed. In Goldsboro, North Carolina, on July 31, 2013, a section of ground was chosen to bury the three caskets. A burial grave was created six feet below the ground surface. A brick and concrete vault was erected to protect the wooden caskets from the weight of both the earth and the heavy maintenance equipment that typically passes over a normal grave.

Nylon rope was tied around each casket handle for easy retrieval purposes. The caskets were then placed within each separate section of the vault and were enclosed with three concrete slabs for added protection. The vault was covered with soil, and three signs were placed over top of the burial site denoting the date and location (Figure 9).

On January 11, 2014, six months after the burial date, the first wooden casket was exhumed and taken to the Goldsboro Eye Clinic for evaluation. The casket was opened, and the contents of the box were found to have been saturated from exposure to ground water. After removing the burial linen, the two enucleated pig eyes were still covered with the plastic lens caps. Contents were photographed using a Sony Cybershot® digital camera.

The lens caps were removed, and the contact lens on each pig eye was carefully inspected, removed with microsurgical forceps and cleaned

with Opti-Free contact lens wetting solution (Figure 10). The inside surface of the left lens cap of the Air Optix® lens demonstrated a blue stain, whereas the right lens cap of the Acuvue 2® lens did not (Figure 11).

On June 30, 2014, 12 months after the initial burial, the second casket was exhumed and examined in the same manner. The wooden casket was caked in dirt, and the metal latch and accents were rusted. Inside the casket, both the Acuvue 2® lens and the Proclear® lens demonstrated increased yellow discoloration compared to the contact lenses exhumed after six months.

The contacts exhibited marked thinning and numerous tears. There was a noticeable loss of tint color on the Proclear® contact lens. On June 20, 2016, 24 months after the initial burial, the final casket was exhumed in the same manner as the other two. The casket was markedly decomposed and encrusted in dirt with a rusted metal latch. Decomposed pig eyes and plastic lid caps were carefully removed from the burial linen. Contact lenses were then lifted from the putrefied cornea of each pig eye with microsurgical forceps. Only in this exhumation were the contacts partially adhered to the degenerative cornea tissue. Using the Opti-Free® contact lens wetting solution, the contact lenses were separated from the decomposed cornea. After the removal of each contact lens and subsequent careful cleaning with the wetting solution, the inner and outer contact lens surfaces were microscopically photographed using a Sony Cybershot® digital camera.

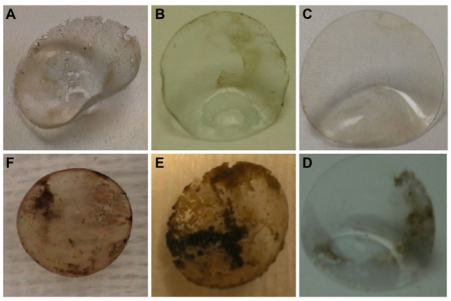

Figure 12: Exhumation results of the various contact lenses: A: Acuvue 2, 6 months B: Air Optix, 6 months
C: Acuvue 2, 12 months D: Proclear, 12 months
E: Acuvue 2, 24 months F: Biofinity, 24 months

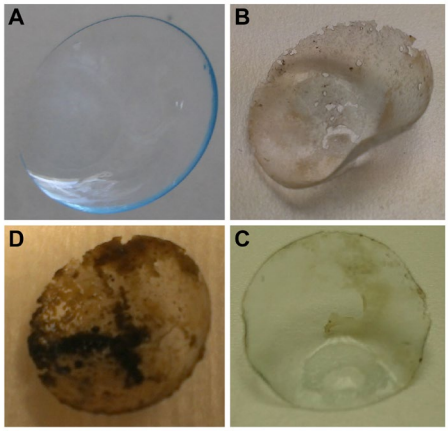

Figure 13: Progressive decomposition of the Acuvue 2 Contact Lens: A. 0 months B. 6 months
Supplementary files
C. 12 months D. 24 months with black particles

Results

In all three exhumations, the soft contact lenses demonstrated thinning, micro tears, and a distinctive yellow-colored discoloration of both the contact lens surface and the internal matrix. The soft contact lenses developed partial and irregular areas of yellowish deposits with a loss of the usual contact lens transparency. The yellowish color on the Acuvue ® 2 contact lenses observed in the 6-, 12-, and 24-month exhumations was consistent with the lens spoilage that was noted on the samples of the material trace evidence in the Abaroa murder case (Table 1) [1].

In the six-month exhumation, the Acuvue 2 lens showed numerous micro-tears and decomposition around the edges. Within the contact lens, yellow deposits were visible in 10% of the overall surface area. The Acuvue 2 contact lens contained no tint and had decomposed by 20%, as demonstrated by the tearing and rough edges (Figure 12). All color changes were measured and estimated by a handheld color checker card.

The Air Optix contact lens only showed a 5% increase in yellow deposits within the lens and decomposed by approximately 10%. The edges were primarily smooth compared to the Acuvue 2. The blue-tinted Air Optix lost 100% of its color due to tint transfer to the plastic lens cap (Figure 12).

At the twelve-month exhumation, the Acuvue 2 lens demonstrated 30% discoloration in yellow deposits compared to 10% in the six-month exhumation. The percentage of lens decomposition (20%) was the same in the six- and twelve-month exhumations for both of the Acuvue 2 lenses. The edges of the Acuvue 2 contact lens were jagged and decomposed, with micro-tears and marked thinning.

In the twelve-month exhumation of the Proclear lens, the yellow deposits in the contact lens measured approximately 35%, which was the highest value observed for any of the contact lenses. The decomposition percentage was approximately 20%, which was similar to the Acuvue 2 lenses. Analogous to the Air Optix lens, the Proclear lens lost 100% of its tint color, which was transferred to the plastic lens cap.

In the 24-month exhumation, the Acuvue 2 contact demonstrated a 35% decomposition of the lens and a 50% yellow discoloration of the contact lens matrix. The Biofinity Toric Tinted contact lens demonstrated a 25% decomposition loss and a 35% yellow discoloration, with a 100% loss of all tint color. In both contact lenses at the two-year exhumation, there were black particle deposits on the surface of the lenses (Figure 12). The black particles were semi-adherent and could be easily washed off the surface of the lenses with balanced saline solution (Figure 13).

In all three burial exhumations, the ocular globes exhibited progressive decomposition and molecular death of the cells. Decomposition represents the post-mortem decay of body tissues due to the surrounding bacteria and other microorganisms from both the host and the environment. Putrefaction is considered the final marker in the stages of somatic death with biochemical destruction of the tissue structure (Figure 14).

Discussion

Margaret Cox, Ph.D., a forensic archeologist, postulated in her 2005 book, Forensic Archaeology: Advances in Theory and Practice, that contact lenses could be used as a forensic tool to identify unknown corpses that are retrieved at unmarked grave sites [8]. With no scientific precedent for the exhumation and evaluation of contact lenses from a

corpse, a burial simulation study was performed to explain the changes observed in the contact lens remnants that were used in the Abaroa murder case. The pig eyeballs that were used in the simulation study were freshly harvested and exhibited the classic somatic changes of early death: loss of corneal transparency, changes in vasculature color, and fixed semi-dilated pupils. The sets of various contact lenses used in the experiment were placed on the corneas within two hours of pig death.

Over the course of the two-year experiment, the exhumations of the globes demonstrated different levels of decomposition. As

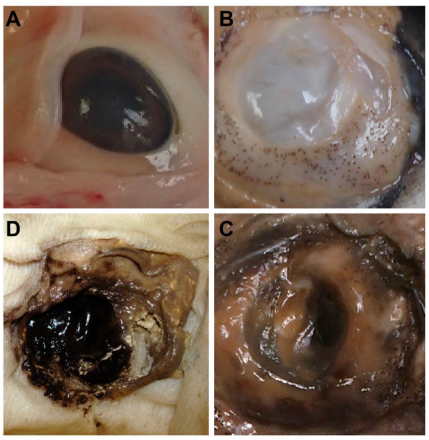

Figure 14: Progressive decomposition of exhumed pig eyeballs: A. 0 months B. 6 months C. 12 months D. 24 months

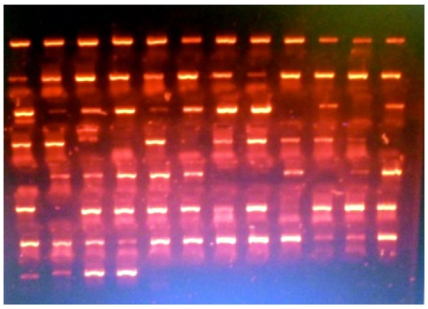

Figure 15: Example of touch DNA amplified sample Instituto de Biología, UNAM, Mexico City.

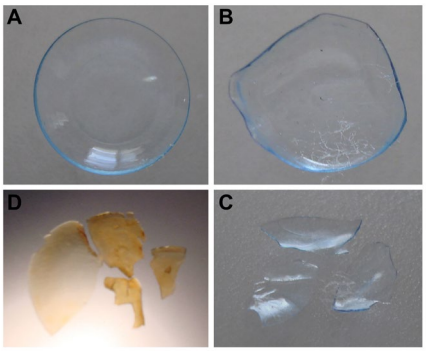

Figure 16: Fracture simulation study using Acuvue 2 contact lens:
A. New Acuvue 2 contact lens
B. Dried with hair blower
C. Fractured into fragments
D. Contact Remnants from Abaroa murder case.

the molecular death time line increased, the putrefaction process continued and affected both the globes and the contact lens material. The putrefaction of the eyeballs was influenced by variable factors, including local microorganisms, temperature, and moisture content of the surrounding soil. Nonetheless, the globes followed the well-established sequence of tissue changes: alteration in tissue color, production of gases, and liquefaction of the tissues.

Most notable in this study was the development of a yellow tint within the contact lenses as a result of tissue saponification and lipid degradation (adipocere formation) [9]. This molecular change begins developing 5-6 months after death and can continue for years, which was consistent with our burial simulation study. Most contact lenses are composed of monomers and cross-linked materials that have electronic charges on the monomers. This charge distribution results in the attraction of proteins and/or lipids that possess electronic-charged surfaces [10]. Thus, the protein and/or lipid materials create a biofilm and deposits within the contact lens. This biofilm of deposits results in the contact lens losing its ocular properties and transparency and assuming a yellow color. This yellow color or lens spoilage is the result of the diffusion of proteins and lipid into the contact lens substrate during tissue saponification and lipid degradation [11-13].

Emerging technologies have been developed that can impact the forensic analysis of contact lenses that are found as material evidence at a crime scene. As noted in the Wright murder case, DNA extraction and amplification allowed the examiner to retrieve DNA from a contact lens specimen. Touch DNA is obtained from epithelial nucleated cells from the cornea, palpebral and/or bulbar conjunctiva that adhere to the surface of the contact lens. According to the *DNA Extraction and Amplification from Soft Contact Lenses Study*, "There have been published case reports in which victims have lost contact lenses during an attack or confinement at a particular location. Soft contact lenses are used by a large portion of American society, and it is very likely that they may be recovered at a crime scene location and become a valuable piece of information in a forensic investigation" Figure 15 [14].

In investigations in which the optical properties of the contact lenses can be determined, Electronic Medical Records (EMR) will be able to assist in the identification process. By creating search software, millions of medical records could be analyzed in seconds to establish a precise documentation of contact lens prescriptions for comparison.

Based on this specific case, other simulation studies may be needed to verify the forensic findings. In addition to the contact lens burial simulation study, a contact lens fracture simulation study in a controlled laboratory environment was performed in the Abaroa murder case (Figure 16) [1].

Based on the findings in the Abaroa case and on the other aforementioned murder cases, contact lens evidence has proven to be pivotal for forensic investigations. A Forensic Contact Lens Procedure has been created to assist investigators in the analysis of contact lenses (Table 2).

Conclusion and Implications

Until recently, there has been no documented forensic research on the use of contact lenses to identify a victim or perpetrator from exhumation. A contact lens burial simulation study was performed to establish and scientifically explain the changes that were noted on the material evidence obtained from the Abaroa exhumation. Due to the physical findings in this murder and material evidence from other criminal cases, there is a need to establish a systematic forensic contact lens procedure. A protocol has been created for future cases

I. Collect Evidence
II. Morphology
A. Size (circumference/diameter)
B. Shape (regular/irregular/fragments)
C. Weight
D. Color
E. Markings
1. Inversion Markings
2. Alignment/Toric Lines
3. Manufacturer Identification Marks
III. Physical Properties
A.Transparency
B. Flexibility
1. Rigid
a. Hard
b. Semi-Soft
2. Soft
C. Refractive Prescription
1. Sphere +/- ; Cylinder +/- ; Axis
2. Base Curve
3. Diameter
4. Tint
D. Chemical Composition by Gas Chromatography - Mass Spectrometry
E. Water Properties
1. Hydrophilic
2. Hydrophobic
F. DNA Extraction and Amplification from Soft Contact Lenses
G. Fingerprint Transfer
H. Foreign Material/ Trace Evidence on Contact Lens Surface
I. Special Computer Software to Extrapolate Contact Lens Dimensions from Remnants
IV. Database
A. Use of Electronic Medical Records (EMR)
1. Correlate Refractive Rx with Specific Patient
2. Identify Prescribing Medical Care Provider
B. Identify Specific Manufacturer Marks or Materials
V. Simulation Studies
A. Reproduce Physical Environment and Condition
B. Laboratory Environment with Software to Create Live Simulation
C. Forensic Animation and Reconstruction Simulations

Table 2: Forensic Contact Lens Procedure.

to collect the evidence; examine the morphology and determine any specific physical properties of the contact; search the databases using electronic medical record (EMR) technology containing contact lens prescriptions and patient information; and perform simulation studies as needed to explain the findings of the material evidence.

References

1. Zwerling CS (2016) Forensic analysis of a contact lens in a murder case. J Forensic Sci 61:534-9.
2. Overgaard T (2012) The grandfather of 35 mm photography.
3. Barr JT (2006) Contact lens spectrum. Annual Report Contact Lenses.
4. Eckert WG (1992) Introduction to forensic sciences. (2nd rev. edn.), CRC Press, Boca Raton, Florida, USA.
5. Bertolli E, Forkiotis C, Pannone D (2006) Ophthalmic appliances in identification: information retrieved from spectacles and contact lenses. JFI 56: 540-548.
6. Wickenheiser RA, Jobin RM (1999) Comparison of DNA recovered from a contact lens using PCR DNA typing. J Can Soc Forensic Sci 32: 67-73.
7. Mayer RG (2012) Embalming: history, theory, and practice (5th edn.), McGraw-Hill Medical, New York, USA.
8. Hunter J, Cox M (2005) Forensic archaeology: Advances in theory and practice. Routledge, London.
9. Panaser A, Tighe BJ (2014) Evidence of lipid degradation during overnight contact lens wear: gas chromatography mass spectrometry as the diagnostic tool. Invest Ophthalmol Vis Sci 55:1797-1804.
10. Bergin J (2000) Introduction to polymers.
11. Friends G, Kunzler J, Ozark RJ (1882) High-strength hydrogels based on *N*-vinyl pyrrolidinone and 4-*t*-butyl-2-hydroxycyclohexylmethacrylate. Biomed Mater Res 26: 59-67.
12. Juniper R, Read P (1994) Biomedical materials. Elseiver, London.
13. Valint PL, Ammon DM, Grobe GL, McGee JA (1997) In situ surface modification of contact lens polymers. In: Ratner BD, Castner DG, editors. Surface modification of polymeric biomaterials. Springer, Boston, USA.
14. Wickenheiser RA, Jobin RM (1999) Comparison of DNA recovered from a contact lens using PCR DNA typing. J Can Soc Forensic Sci 32: 67-73.