Pathological and Toxicological Investigations of Keith Warren's Death

Conducted by:
Dr. Mohammed Ali Al-Bayati
Ph.D., DABT, DABVT
Toxicologist & Pathologist

Toxi-Health International
4800 Kokomo Dr. # 2215
Sacramento, CA 95835
Phone: (916) 575-8877
Fax: (916) 285-0689
maalbayati@toxi-health.com

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Abstract:

On July 31, 1986, Keith Warren, a 19-year-old black male, was found hanging from a small tree in a park in Silver Spring, Maryland. Police and the County Medical Examiner ruled Keith's death a suicide and his body was sent to Collins Funeral Home in Silver Spring for embalming without performing an autopsy.

Suspicious events led the family to exhume Keith's body on May 24, 1994 and Dr. Isidore Mihalakis performed the autopsy of Keith's body. High levels of 1, 1, 1-Trichloroethane (TCE) and 1, 1-Dichloroethane (DCE) were found in Keith's blood, brain, liver, kidney, and muscles. Xylene, ethylbenzene, and toluene were also detected in these tissues but at low concentrations. Mihalakis stated that the cause of death was undetermined. My investigation in this case reveals the followings:

1) Keith had a lethal level of TCE and a toxic level of DCE in his blood, brain, liver, kidney, and muscles. The concentrations and the pattern of TCE and DCE distribution in tissues indicate that Keith received these chemicals at about 1-2 hours prior to his death via ingestion and they were likely mixed with alcoholic drinks. The estimated ingested doses of TCE and DCE in Keith's case are 94.94 g (70.85 mL) and 21.48 g (18.28 mL), respectively.

The ingestion of high doses of TCE and DCE lead to vomiting, diarrhea, central nervous system (CNS) depression, and aspiration pneumonia. Mihalakis examined H & E stained sections of Keith's trachea, larynx, and lungs microscopically. He found aspirated materials in the larynx and trachea and congestion and edema in the lungs.

2) The autopsy showed no hemorrhages, soft tissue injury, dislocation or fractures in Keith's neck. In addition, Keith's tongue, larynx, laryngeal cartilages, hyoid bone as well as his cervical vertebral column visually were without injuries. The lack of bleeding and injury in Keith's neck indicate that Keith's body was lifted and put in a hanging position a few hours after his death, when the muscles of the neck became stiff due to rigor mortis.

3) The police and the county medical examiner missed the cause of death in Keith's case because they did not conduct the required standard medical-legal investigation in his case.

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Summary of the case and findings

On July 31, 1986, Keith Warren, a 19-year-old black male, was found hanging from a small tree in a park behind his house in Silver Spring, Maryland. A girl was walking in the park, discovered his body and called 911. Rescue personnel arrived on the scene and the paramedic made close observations of the body and determined that Keith was dead.

Montgomery County Police Officer Luther Leverette from the Wheaton-Glenmont Police Station responded to the scene and took charge. He contacted the medical examiner office and Keith's death ruled a suicide. His body was sent to Collins Funeral Home in Silver Spring for embalming without performing an autopsy.

At first, Keith's family accepted the police's ruling that Keith had committed suicide, but as time progressed, several suspicious occurrences that happened before and after Keith's death made his family suspect that he may have been murdered. In particular, on April 9, 1992, Keith's mother found a plain vanilla envelope inside the screen door of her house, containing 5 crime-scene photos showing Keith was hanging from a tree with his head bent to the right. The police department conceded that they were copies of original police photos, but they had no idea where they came from. Keith's mother noticed that Keith was not wearing his own clothing. The original photos were not shared with Keith's mother in 1986.

These suspicious events led to the family's decision to exhume Keith's body and arrange for an autopsy. The funeral home exhumed Keith's body on May 24, 1994 and the body was flown to Bethlehem, Pennsylvania. Dr. Isidore Mihalakis performed the autopsy of Keith's body on May 26, 1994.

High levels of 1, 1, 1-Trichloroethane (TCE) and 1, 1-Dichloroethane (DCE) were found in Keith's blood, brain, liver, kidney, and muscles. Low concentrations of xylene, ethylbenzene, and toluene were also detected in these tissues. These solvents are not normal constituents of embalming fluids or decompositional effect.

Dr. Mihalakis stated that the cause of death was undetermined, even though Keith was found hanging from a tree limb with his feet touching the ground and knees bent. Toxicologic findings are incompatible with the autopsy findings, and do not support a hanging diagnosis. He also stated that, "the scene investigation and the handling of the body immediately afterward, based on my previous communiqué was inappropriate and not in accordance with accepted standards of a good medical-legal investigation system".

Keith's sister contacted me in November of 2011 and requested that I review Keith's autopsy report and other medical and legal records generated in his case and provide an opinion concerning the likely cause(s) of his death. I am a toxicologist and pathologist with over 25 years experience in these fields. I have evaluated the medical records regarding cases of adults and children who died suddenly from unexplained causes and cases of children and adults who suffered from acute and/or chronic illnesses.

I am able to explain the causes of illness and death in these cases by using differential diagnosis. I have also served as an expert witness in many medical-legal cases involving children and adults, and have published over 50 articles in medical and scientific journals.

I evaluated Keith's autopsy and toxicology reports and the pertinent documents and articles cited in this report using differential diagnosis. My investigation in this case reveals the followings:

1) The toxicological data and observations described in Sections III & IV of this report and briefly listed below show that Keith died as result of receiving a lethal dose of 1, 1, 1-Trichloroethane (TCE) and a toxic dose of 1, 1-Dichloroethane (DCE) via ingestion at about 1-2 hours prior to his death and it is likely that these chemicals were mixed with alcohol.

a) The high concentrations of TCE and DCE in Keith's blood, brain, liver, kidney, and muscle indicate that he was exposed to a lethal dose of TCE and a toxic dose of DCE acutely prior to his death. The presence of TCE in the blood of an individual at a concentration above 1.0 to 1.5 mg/dL is considered as a lethal level. The concentration of TCE in Keith's dry blood was 6 mg/dL. The estimated dose of TCE and DCE received in Keith's case was 116 g, which is a lethal dose (Table 18). TCE and DCE cause central nervous system (CNS) depression and they have anesthetic effects.

b) The distribution pattern of TCE and DCE in Keith's tissues indicates that Keith was exposed to these solvents acutely prior to his death. The distributions of these solvents in Keith's tissues were influenced by their doses and solubility in lipids. The brain has the highest concentrations of solvents relative to the blood because of their high solubility in lipids as shown in Table 18.

c) The concentrations of TCE and DEC in Keith's liver relative to the blood were 2.67 and 6.29, respectively (Table 18). The high concentrations of TCE and DCE in Keith's liver relative to the blood indicate that Keith received these chemicals via ingestion prior to his death. Solvents were absorbed via the gastrointestinal mucosa and reached the liver via portal circulation. The concentration of DCE in Keith's liver relative to the blood is 2.35 folds higher than those of TCE, which indicates that their uptake was influenced by the ingested dose.

d) The ingestion of high doses of TCE and DCE cause irritation of the gastrointestinal tract (GI) and leads to vomiting. The absorption of TCE and DCE through the gastrointestinal tract (GI) produces central nervous system (CNS) depression proportional to the amount absorbed. Vomiting and CNS depression lead to the aspiration of materials present in the GI to the lungs. The microscopic examination of H & E stained sections of Keith's trachea and the larynx showed the presence of aspirated materials (Section II).

Furthermore, 90% of the ingested TCE and DCE are eliminated from the body via the lungs. The elimination of toxic levels of these chemicals via the lungs causes congestion and edema. The examination of H & E stained sections of Keith's lungs showed congestion and edema (Section II-C). These observations also indicate that Keith ingested high doses of TCE and DCE chemicals during 1-2 hours prior to his death.

e) The high concentrations of TCE and DCE in Keith tissues and their low solubility in water indicate that these chemicals were likely mixed with alcoholic drinks and given to Keith. TCE and DCE are slightly soluble in water (0.4-0.5 g/dL) and very soluble in alcohol and organic solvents (Table 5). The estimated dose of TCE and DCE received in Keith's case was 116 g. It would require more than 23 liters of water to completely dissolve 116 g of TCE and DCE, which makes water alone, an unlikely vehicle.

Empty wine cooler bottles were found in a densely wooded area where Keith was found hanging from a tree. Wine cooler drinks usually contain 4-7% alcohol and are mixed with fruit juices. They can be used as a vehicle to increase the solubility of TCE and DCE in water and mask their taste. Alcohol also increases the rate of absorption of TCE and DCE from the gastrointestinal tract, which explains the presence of high concentrations of these chemicals in Keith's tissues.

2) The concentrations of xylene, ethylbenzene, and toluene in Keith's tissues and their pattern of distribution indicate that Keith was exposed to these chemicals via ingestion prior to his death. Their distribution in tissues is influenced by their doses and solubility in lipids. The brain has the highest concentrations of these compounds relative to blood.

The concentrations of xylene, ethylbenzene, and toluene in Keith's liver relative to the blood indicate that Keith received these chemicals via ingestion (Table 18). These solvents were absorbed via the gastrointestinal mucosa and reached the liver via portal circulation. These observations also indicate that Keith ingested these chemicals while he was alive (Sections III & IV).

3) The estimated volume of the TCE and DCE mixture ingested in Keith's case is 89 mL, which consists of 79.5% TCE and 20.5% DCE. The U.S. Naval Research Laboratory analyzed technical grade TCE purchased in 1965 from 4 companies. Their analyses showed that one of them contained 65% TCE, 22% dichloroethane, and 0% dioxane. It was purchased from Octagon Process Company (Table 16). Octagon's technical grade TCE has a similar composition to the organochlorine solvents mixture recovered from Keith's tissues.

Most of the technical grade TCE sold in the USA contains about 94% TCE and 6% stabilizers such as epoxides and amines to prevent dehydrochlorination of TCE and the reaction of TCE with metals. However, no dioxane was present in Keith's blood and tissues. These data indicate that TCE used in Keith's case was not purchased to clean metals and it was likely used as a cleaner for photographic film.

Keith's mother found a plain vanilla envelope inside the screen door of her house on April 9, 1992, which is about 6 years after Keith's death. It contained 5 crime-scene

photos showing Keith was hanging from a tree. The police department conceded that they were copies of original police photos, but they had no idea where they came from. It is possible that there is a link between the individual who produced a copy of the crime-scene photos and the individual who purchased the TCE used in Keith's case. TCE is used as cleaner for photographic film (Sections III & IV).

4) The estimated volume of xylene, ethylbenzene, and toluene mixture ingested by Keith is 1.7 mL. It consists of 73.9% xylenes, 20.5% eththylbenzene, 5.52% toluene, which is similar to the composition of the technical grade xylene that contain about 80% xylenes, 20% ethylebenzene as well as a small quantity of toluene. It is possible that the technical grade TCE used in Keith's case also contains 2% technical xylene or the technical grade xylene was added to TCE to enhance their solubility in water. Xylene is also used as a solvent in the printing industry (Sections III & IV).

5) Autopsy studies of suicide hanging cases have shown injuries to the neck soft tissues, bones, and organs in the majority of the cases and bleeding in the soft tissues of the neck in all cases as described in Section V-A. The autopsy showed no hemorrhages, soft tissue injury, dislocation or fractures in Keith's neck. In addition, Keith's tongue, larynx, laryngeal cartilages, hyoid bone as well as his cervical vertebral column visually were without injuries other than some autolytic changes (Section II-B).

The lack of bleeding and injury in Keith's neck can be explained by the following medical evidence: 1) Keith died as a result of ingesting a lethal dose of organochlorine solvents as described above and in Sections III and IV of this report; 2) Keith's body was lifted and put in a hanging position a few hours after death, when the muscles of the neck became stiff due to rigor mortis.

6) The police and the County Medical Examiner missed the cause of death in Keith's case because they did not conduct the required standard medical-legal investigation in his case as described in Section V-B of this report and briefly listed below:

a) The police did not take fingerprints from the knot on Keith's neck and the portion of the ropes tied to the base of the big tree to see if other individual(s) tied these ropes.

b) No autopsy was conducted or blood and tissues samples were taken to perform toxicological analyses to rule out other cause(s) of death.

c) Keith's body was sent to a funeral home and his body was embalmed prior to allowing his mother to view the body. In 1992, Keith's mother received 5 crime-scene photos showing Keith was hanging from a tree. She noticed that Keith was not wearing his own clothing, which indicates that key information for the investigation was missed.

It is likely that Keith's body was washed after death and his clothes were changed because they became dirty with vomit and possibly with fecal materials. Keith ingested a lethal dose of organochlorine solvents mixed with alcohol, which caused him to vomit as indicated by the presence of aspirated materials in Keith's trachea and the larynx. Ingestion of toxic levels of organochlorine solvents also cause diarrhea.

d) Embalming Keith's body also interfered with the collection of important medical evidence. The contents of the stomach and the intestine were removed. Dr. Mihalakis stated that Keith's viscera were extensively trocared and the stomach contained minimal granular non-recognizable material. Therefore, it was not possible to take samples from the stomach and the rest of the gastrointestinal tract to perform toxicological analysis.

Section I. Keith's hanging scene, police investigation, and exhumation of his body at 8 years following death to perform an autopsy

On July 31, 1986, Keith Warren, a black male, was found hanging from a small tree in a park behind his house in Silver Spring, Maryland. Keith was living with his mother and sister. He was 19 years old at the time of his death. He was born on April 9, 1967 in Topeka Kansas.

A girl was walking her dog in the park, found Keith's body hanging from a tree and called 911. Rescue personnel arrived on the scene with paramedic Dallas Lipp in charge. Lipp made close observations of the body and determined that Keith was dead [1]. Montgomery County Police Officer Luther Leverette from the Wheaton-Glenmont Police Station responded to the scene and took charge.

Leverette put the time of Keith's death as of 1405 on July 30, 1986 and contacted the County Medical Examiner Office. Keith's death was ruled a suicide and his body sent to Collins Funeral Home in Silver Spring for embalming without performing an autopsy [2, 3].

Keith's mother reported that she went with her brother to the funeral home on July 31st to identify the body, but they were denied entry three times and told to come back the next day. Twenty-four hours later, on the fourth attempt, they went to the funeral home and were finally allowed to briefly view Keith's remains after he had been embalmed [4].

With respect to the hanging scene, the rope used in the hanging was thrown through a fork where a branch came off a tree approximately 18 feet above the ground. The tree was four to six inches in diameter at the base. At the base of the tree, the rope was wound

around the trunk several times, and from there it went fifteen to twenty feet away remaining about a foot off the ground and was tied to another larger tree [1, 3].

The family maintained that Keith was not suicidal and there seemed to be no reason for him to commit suicide. There was no suicide note found in the park**.** Keith had recently graduated (June 1986) from John F Kennedy High School in Wheaton, Maryland and was preparing to enter North Carolina Central University in Durham in the fall of 1986. Keith had a summer job working at Glenmont Chrysler and Bel Pre Shell [3, 4].

Keith left home on Tuesday, July 29, 1986 to spend time with friends. His mother became concerned when he did not return home on July 30th and called around to inquire about Keith, but to no avail. Then, she notified the Montgomery County Police at the Wheaton/Glenmont Station. She was informed that unless he was an invalid or on medication, they would not look for him until 48 hours had passed [4].

At first, Keith's family accepted the police's ruling that Keith had committed suicide, but as time progressed, several suspicious occurrences that happened before and after Keith's death made his family suspect that he may have been murdered. In particular, on April 9, 1992, Keith's mother found a plain vanilla envelope inside the screen door of her house, containing 5 crime-scene photos showing Keith was hanging from a tree with his head bent to the right. The police department conceded that they were copies of original police photos, but they had no idea where they came from. Keith's mother noticed that Keith was not wearing his own clothing. The original photos were not shared with Keith's mother in 1986 [3, 4].

These suspicious events led to the family's decision to exhume Keith's body and arrange for an autopsy. The funeral home exhumed Keith's body on May 24, 1994 and the body

was flown to Bethlehem, Pennsylvania. Dr. Isidore Mihalakis performed the autopsy of Keith's body on May 26, 1994.

High levels of 1, 1, 1-Trichloroethane and 1, 1-Dichloroethane were found in Keith's blood, brain, liver, kidney, and muscles and these organochlorine solvents are not normal constituents of embalming fluids or decompositional effect. Dr. Mihalakis stated that the cause of death was undetermined, even though Keith was found hanging from a tree limb with feet touching the ground and knees bent, because toxicologic findings are incompatible with the autopsy findings, and in fact do not support a hanging diagnosis [3].

He also stated that "the scene investigation and the handling of the body immediately afterward, based on my previous communiqué was inappropriate and not in accordance with accepted standards of a good medical-legal investigation system" [3]. The autopsy findings and their significance are described in Section II of this report.

Section II. Autopsy, pathology, and toxicology findings in Keith's case and their indications

The funeral home exhumed Keith's body on May 24, 1994 and the body was flown to Bethlehem, Pennsylvania. Dr. Isidore Mihalakis performed the autopsy at Lehigh Valley Hospital on May 26, 1994, which is about 8 years after Keith's death. Keith's body measured five feet ten inches tall and weighed approximately 140 to 150 pounds. The body was previously embalmed [3].

Prior to autopsy, Keith's body was examined by X-ray and no evidence of broken bone was observed. Dr. Mihalakis examined Keith's body grossly and conducted an autopsy. He examined all organs grossly and microscopically. In addition, samples from Keith's coagulated blood, brain, liver, kidney, and, muscles were analyzed for the presence of selected toxic solvents and other elements. The main autopsy, pathology, and toxicology findings include:

1) No sign of a struggle, defensive wounds, or injection sites were found in Keith's case. There was also no ligature marks about his wrists or ankles noted as described in Section II-A.

2) There were no fractures, dislocations, or hemorrhages in Keith's neck. In addition, Keith's tongue, larynx, laryngeal cartilages, hyoid bone and soft tissues of the neck as well as his cervical vertebral column visually were without injuries other than some autolytic changes (Section II-B).

3) The gross and microscopic examinations of Keith's brain, heart, liver, kidneys, spleen, testes, and other tissues did not show that Keith was suffering from an acute or a chronic medical problem or cancer. However, the microscopic examination of sections of the

trachea and the larynx showed the presence of aspirated materials and sections of the lung showed congestion and edema (Section II-C).

4) The toxicological analyses of Keith's blood, brain, liver, kidney, and muscles revealed the presence of a lethal level of 1, 1, 1-Trichloroethanol (TCE) and a toxic level of 1, 1-Dichloroethanol (DCE). Other organic solvents at lower concentrations were also detected in Keith's tissues (Sections II-D).

Dr. Mihalakis stated that the cause of death was undetermined even though Keith was found hanging from a tree limb with his feet touching the ground and knees bent. Toxicologic findings are incompatible. I evaluated the autopsy, pathology, and toxicology findings and the pertinent medical literature to Keith's case using differential diagnosis. My investigation reveals that Keith died as a result of exposure to a lethal dose of 1, 1, 1-Trichloroethanol and a toxic dose of 1, 1-Dichloroethanol via ingestion and the hanging of his body occurred after death as described in Sections III-V of this report.

II-A. No evidence of injuries indicating struggle, injection sites, and ligature marks

Prior to autopsy, Keith's body was examined by X-ray and no evidence of bone fracture was found. Dr. Mihalakis examined Keith's body externally and found no lesions other than skin slippage. His examination revealed no sign of a struggle or defensive wounds as indicated by the following observations: 1) The scalp was unremarkable and there were no bruises; 2) no lesions were noted of the nose, the ears, the cheeks, and the labial or buccal musosa; 3) the upper extremities, hands, fingers and fingernails were unremarkable; 4) the lower extremities and the toes were without note; and 5) the back was unremarkable.

In addition, Keith's skin was scraped in the legs, the back, and the arms in an effort to look for any possible undue hemorrhages indicative of any bruising and no such hemorrhages were identified. There were also no subcutaneous hemorrhages to indicate any injection sites and no ligature marks about the wrists or ankles. The police had also stated that there were no signs of a struggle at the suburban park where Keith's body was found [3].

II-B. No evidence of injuries to the neck region

The external examination of Keith's neck by Dr. Mihalakis showed diffuse skin slippage and remnants of a noose mark but no injuries indicating trauma. In the region of the ligature groove, no hemorrhages were noted circumferentially about Keith's neck. The entire dissection of the neck region in Keith's case did not reveal evidence of bleeding, tissue damage indicating trauma, dislocation of vertebrae, or bone fractures. His hyoid bone and the horns were intact as well as the thyroid cartilage and its horns. His tongue, larynx, and laryngeal cartilages were also unremarkable. Some autolytic changes were observed in the tissues.

The microscopic examination of the H & E stained tissue sections of the skin and muscles showed the epidermis, dermis, and skeletal muscle were essentially unremarkable except for postmortem degenerative change. Sections of the skin and soft tissues from the noose groove revealed fibrofatty tissue and skeletal muscle with no unusual histological features other than postmortem degenerative change [3].

II-C. Examination of tissues and organs showed no evidence of illness or cancer

Dr. Mihalakis examined Keith's body cavities, organs, and tissues grossly and did not see any evidence of an acute or chronic illness, cancer, or injury indicating trauma. The weights of Keith's organs were within the normal range (Table 1). Keith's musculoskeletal system showed excellent growth and development.

The microscopic examinations of the H & E stained tissue sections of organs did not reveal evidence of an acute or chronic illness or cancer. However, the microscopic examination of sections of the trachea and the larynx showed the presence of aspirated materials and sections of the lung showed congestion and edema. All tissues showed postmortem degenerative changes.

Table 1. Keith's organ weight (g) and as % of body weight

Organs	Weight (g)	% of body weight*
Brain	550	0.83
Heart	300	0.46
Right lung	420	0.64
Left lung	390	0.59
Liver	1300	1.97
Pancreas	50	0.08
Spleen	160	0.24
R. Kidney	140	0.21
L. Kidney	120	0.18

* Keith's body weight 140-150 Lb, Ave 145 (65.9 kg)

II-D. Concentrations of organic solvents and other elements detected in Keith's tissues

Dr. Mihalakis took samples of Keith's coagulated blood, brain, liver, kidney, and muscles and sent them for toxicological analyses. A lethal level of 1, 1, 1-Trichloroethane (TCE) and a toxic level of 1, 1-Dichloroethane (DCE) were detected in Keith's blood, brain, liver, kidney, and muscles. Other solvents also present at lower concentrations in his tissues (Tables 2). These solvents are not normal constituents of embalming fluids or decompositional effect.

The high concentrations of solvents present in the tissues indicate that Keith received a lethal dose of TCE and a toxic dose of DCE via ingestion, which led to his death. It is likely that these solvents were mixed with alcoholic drinks such as wine cooler to increase their solubility in water and their absorption from the gastrointestinal tract and to mask their taste. Wine cooler drinks usually contain 4-7% alcohol and are mixed with fruit juices. The toxicological data and analysis and the supportive studies regarding Keith's ingestion of solvents are described in section III of this report.

Arsenic, boron, copper, nickel, selenium, and zinc were also detected in Keith's blood and liver. The concentrations of all elements in his blood and liver, except arsenic, were within the background levels and without toxicological significance (Table 3). The concentration of arsenic in Keith's blood and liver seems higher than the background level but without toxicological significance. A higher concentration of arsenic (0.59 μg arsenic/g of tissue) has been reported in the arterial tissues of healthy people [5].

Table 2. Concentrations of solvents (µg/g) detected in Keith's blood and tissues at the time of autopsy (May 2, 1994)

Solvents	µg/g Dry Blood	µg/g Liver	µg/g Kidney	µg/g Brain	µg/g Muscles
1, 1, 1, Trichloroethane ($C_2H_3Cl_3$)	60	80	83	310	130
1, 1 Dichloroethane ($C_2H_4Cl_2$)	14	44	22	88	32
Xylenes [$C_6H_4(CH_3)_2$]	1.4	10	2.1	20	10
Ethylbenzene ($C_6H_5CH_2CH_3$)	0.8	2.0	0.7	6.6	4.7
Toluene (C_7H_8)	0.8	1.6	0.4	1.9	1.2

Table 3. Concentrations (µg/g) of elements detected in Keith's blood and liver

Elements	µg/g dry blood	µg/g liver
Arsenic	0.28	0.17
Boron	3.50	4.7
Copper	5.40	2.2
Nickel	5.50	0.25
Selenium	0.36	0.19
Zinc	29.0	38

Section III. Concentrations and distributions of organochlorine and other solvents detected in Keith's tissues, estimated doses received, and the likely route of exposure

Blood and tissue samples were taken at autopsy and analyzed for organochlorine and other organic solvents. The autopsy in Keith's case was performed on May 26, 1994, which is about 8 years after Keith's death [3]. The results of the analysis revealed the followings:

1) Keith had a lethal level of 1, 1, 1-Trichloroethane (TCE) and a toxic level of 1, 1-Dichloroethane (DCE) in his blood, brain, liver, kidney, and muscles. The concentrations and the pattern of TCE and DCE distribution in tissues indicate that Keith received these chemicals at about 1-2 hours prior to his death via ingestion and they were likely mixed with alcoholic drinks (Section III-A). The estimated ingested doses of TCE and DCE in Keith's case are 94.94 g (70.85 mL) and 21.48 g (18.28 mL), respectively (Section III-B)

2) Xylene, ethylbenzene, and toluene were also detected in Keith's blood and other tissues. The pattern of distribution of these solvents in tissues indicates that Keith received these chemicals via ingestion while he was alive (Section III-C). The estimated volume of xylene, ethylbenzene, and toluene was likely ingested by Keith is 1.7 mL (Section IV-D).

3) It is estimated that Keith ingested about 91 mL of a mixture that consists of 98% organochlorine solvents and about 2% xylene mixed with ethylbenzene and toluene (Section III-E).

III-A. Distribution of organochlorine solvents in Keith's tissues and their indications

The concentrations of 1, 1, 1-Trichloroethane (TCE) and 1, 1-Dichroethane (DCE) detected in Keith's blood and tissues at the time of autopsy and their pattern of distribution relative to the blood are presented in Table 4. These data reveal the followings:

1) Keith had a lethal level of TCE and a toxic level of DCE in his blood, brain, liver, kidney, and muscles. The presence of TCE in the blood of an individual at a concentration above 1.0 to 1.5 mg/dL would be consistent with death [6]. The concentration of TCE in Keith's dry blood was 6 mg/dL (Table 4).

2) The distributions of TCE and DCE in Keith's tissues were influenced by their doses received and solubility in lipids. The brain has the highest concentrations of TCE and DCE relative to the blood (Table 4). TCE and DCE are soluble in lipids and slightly soluble in water (Table 5). The pattern of TCE and DCE distribution in tissues indicates that Keith received these chemicals while he was alive and their concentrations in tissues indicate that he was exposed to these chemicals for about 1-2 hours prior to his death.

3) The concentrations of TCE and DEC in Keith's liver relative to the blood were 2.67 and 6.29, respectively. The high concentrations of TCE and DCE in Keith's liver relative to the blood indicate that Keith received these chemicals via ingestion. These chemicals were absorbed via the gastrointestinal mucosa and reached the liver via portal circulation. The concentration of DCE in Keith's liver relative to the blood is 2.35 folds higher than those of TCE, which indicate that their uptakes were influenced by the dose ingested (Table 4). These observations also indicate that Keith ingested these chemicals, while he was alive.

In addition, excessive absorption of TCE and DCE through the gastrointestinal tract (GI) produces central nervous system (CNS) depression proportional to the amount absorbed and they have anesthetic effects. They also cause vomiting and aspiration of materials present in the GI to the lungs. The microscopic examination of H & E stained sections of the trachea and the larynx showed the presence of aspirated materials.

Furthermore, 90% of the ingested TCE and DCE is eliminated from the body via the lung. The elimination of toxic levels of these chemicals via the lung causes congestion and edema. The examination of H & E stained sections of Keith's lung showed congestion and edema (Section II-C). These data also indicated that Keith ingested these chemicals during 1-2 hours prior to his death.

4) TCE and DCE are slightly soluble in water and very soluble in alcohol and organic solvents (Table 5). The high concentrations of TCE and DCE in tissues indicate that these chemicals were likely mixed with alcoholic drinks to increase their solubility in water and their absorption from the gastrointestinal tract. Empty wine cooler bottles were found in the park where Keith was found hanging from the tree [4]. Wine cooler drinks usually contain 4-7% alcohol and are mixed with fruit juices. They can be used as a vehicle to increase the solubility of TCE and DCE in water and mask their taste.

Table 4. Concentrations of TCE (1) and DCE (2) in Keith's tissues, their distribution relative to the blood (3, 4) and the ratio of TCE concentration to DCE concentration in tissues (5)

Organ	TCE µg/g Tissue (1)	DCE µg/g Tissue (2)	TCE Tissue / Blood (3)	DCE Tissue/ Blood (4)	TCE (1) /DCE (2) (5)
Dry blood	60	14	2	2	4.28
Liquid Blood*	30	7	1	1	4.28
Brain	310	88	10.33	12.57	3.52
Liver	80	44	2.67	6.29	1.81
Kidneys	83	22	2.76	3.14	3.77
Muscles	130	32	4.33	4.57	4.06

* Concentration in liquid blood = concentration in dry blood/2

Table 5. Physical and chemical properties of 1, 1, 1-Trichloroethane and 1, 1-Dichloroethane detected in Keith's tissues*

Measurements	1, 1, 1-Trichloroethane ($C_2H_3Cl_3$)	1, 1-Dichloroethane ($C_2H_4Cl_2$
Color/ Smell	Colorless, sweet-smelling liquid.	Colorless, oily liquid with chloroform like odor.
MW (mol/g)	133.40	98.97
Density g/cm^3 at 20 ^oC	1.34 at 20 ^oC	1.175 at 20 ^oC
Solubility in water (g/dL)	0.44 at 20 ^oC	0.509
Partition coefficients Log K_{ow}	2.49	1.79

* [References # 7-12]

III-B. Estimated doses of TCE and DCE likely ingested by Keith

The estimated tissues and body burden of 1, 1, 1-Trichloroethane (TCE) and 1,1-Dichloroethane (DCE) at the time of Keith's autopsy on May 26, 1994 are presented in Tables 6 and 7, respectively. The following equations and assumptions are used to calculate the total tissues and body burden of TCE and DCE in Keith's case:

Equations:

1) Total blood burden (mg) = Concentration in dry blood (µg/g) x 65.9 kg x 7/200.
2) Total muscles burden (mg) = Concentration in muscles (µg/g) x 65.9 kg x 40/100.
3) Total fat burden (mg) = Concentration in brain (µg/g) x 65.9 kg x 20/100.
4) Total burden (mg) in the remaining tissues (bone, connective tissues, and other soft tissues that are not included in other estimation = [Concentration in muscles (µg/g) + Concentration (µg/g) in fresh blood] x 19.6 kg (weight of tissues)/2
5) Total body burden (mg) = Total solvent (mg) present in all tissues.

Assumptions: The following assumptions are used in the above equations:

1) Keith's body weight is 65.9 kg (145 lb).
2) Total blood (kg) = 7 x 65.9 kg/100
3) Concentration of solvent in fresh blood (µg/g) = Concentration of solvent in dry blood (µg/g)/2.
4) Total muscles (kg) = 40 x 65.9 kg/100
5) Total fat (kg) = 20 x 65.9 kg/100
6) Solvent concentration in fat (µg/g)= Solvent concentration in the brain (µg/g).
7) The concentration of solvent in the other tissues (µg/g) = (concentration of solvent in muscle (µg/g) + concentration of solvent in fresh blood (µg/g)/2.
8) The weight of other tissues (kg) = body weight (65.9 kg) – 46.3 kg (weights of brain, liver, kidneys, muscles, fat, and blood).

The estimated level of Keith's body burden of TCE and DCE at the time of autopsy is 9,494 and 2,148 mg, respectively (Tables 6, 7). It has been reported that about 90% of the ingested TCE or DCE is exhaled via the lung [10]. The estimated ingested doses of TCE and DCE in Keith's case are 94.94 g (70.85 mL) and 21.48 g (18.28 mL), respectively (Table 8).

Table 6. Keith's tissues and body burden of 1, 1, 1-Trichloroethane (TCE) at the time of autopsy (estimated)

Organ/tissue	Concentration (μg TCE/g Tissue)	Organ Or tissue Weight (kg)	Total TCE (mg)/organ
Dry Blood	60	4.61	138
Brain	310	0.55	171
Liver	80	1.30	104
Kidneys	83	0.26	22
Muscles	130	26.4	3427
Fat	310	13.18	4,086
Skin, bone, and others tissues	80	19.6	1,568
Total		65.9	9,494

* 145 Lb (65.9 kg)

Table 7. Keith's tissues and body burden of 1, 1-Dichloroethane (DCE) at the time of autopsy (estimated)

Organ/tissue	Concentration (µg DCE/g Tissue)	Organ Or tissue Weight (kg)	Total DCE (mg)/organ
Dry Blood	14	4.61	32
Brain	88	0.55	48
Liver	44	1.30	57
Kidneys	22	0.26	6
Muscles	32	26.4	845
Fat	88	13.18	1,160
Skin, bone, and others tissues	19.5	19.6	382
Total		65.9	2,148

* 145 Lb (65.9 kg)

Table 8. The estimated ingested doses of TCE and DCE in Keith's case

Measurements	TCE	DCE
Estimated body burden at the time of autopsy (g)	9.494	2.148
Estimated % of the dose exhaled	90	90
Estimated g ingested	94.94	21.48
Density (g/mL)	1.34	1.175
Estimated mL ingested	70.85	18.28

III-C. Distribution of xylene, ethylbenzene, and toluene in tissues and their indications

The concentrations of xylene, ethylbenzene, and toluene detected in Keith's blood and tissues at the time of autopsy and their pattern of distribution relative to blood are presented in Table 9. These data reveal the following:

1) The distributions of xylene, ethylbenzene, and toluene in Keith's tissues were influenced by their doses and solubility in lipids. The brain has the highest concentration of these compounds relative to blood (Table 9). Xylene is insoluble in water. The solubility of ethyl benzene in water is trace and toluene is slightly soluble in water (Table 10). The pattern of xylene, ethylbenzene, and toluene distribution in tissues indicates that Keith received these chemicals while he was alive.

2) The concentrations of xylene, ethylbenzene, and toluene in Keith's liver relative to the blood indicate that Keith received these chemicals via ingestion. These chemicals were absorbed via the gastrointestinal mucosa and reached the liver via portal circulation. These observations also indicate that Keith ingested these chemicals, while he was alive.

Table 9. Concentrations of Xylene (1), Ethylbenzene (2), and Toluene (3) in Keith's Tissues and their distribution relative to blood (4, 5, 6)

Organ	Xylene µg/g Tissue (1)	Ethyl benzene µg/g Tissue (2)	Toluene µg/g Tissue (3)	Xylene Tissue/ Blood (4)	E. benzene Tissue/ Blood (5)	Toluene Tissue/ Blood (6)
Dry blood	1.4	0.8	0.8	2	2	2
Liquid Blood	0.7	0.4	0.4	1	1	1
Brain	20	6.6	1.9	28.6	16.5	4.8
Liver	10	2.0	1.6	14.3	5.0	4.0
Kidneys	2.1	0.7	0.4	3.0	1.8	1.0
Muscles	10	4.7	1.2	14.3	11.8	3.0

Table 10. Physical and chemical properties of solvents detected in Keith's tissues*

Solvents	Color/ Smell	MW (mol/g)	Density g/cm^3 at 20 ^oC	Solubility In water (g/dL)	Partition coefficients Log K_{ow}
Xylenes $[C_6H_4(CH_3)_2]$	Colorless, sweet-smelling liquid	106.16	0.864	Insoluble	3.12-3.20
Ethylbenzene $(C_6H_5CH_2CH_3)$	Colorless liquid with a sweet, gasoline-like odor	106.17	0.867	0.014	3.15
Toluene (C_7H_8)	Colorless liquid with a sweet, benzene-like odor	92.14	0.866	Slightly 0.047	2.69

* References # [13, 14, 15].

III-D. Estimated doses of xylene, ethylbenzene, and toluene likely ingested by Keith

The estimated tissues and body burden of xylene, ethylbenzene, and toluene at the time of Keith's autopsy on May 26, 1994 are presented in Tables 11, 12, and 13, respectively. The equations and assumptions are used to calculate the total tissues and body burden of xylene, ethylbenzene, and toluene are described in (Section III-B).

The estimated doses of xylene, ethylbenzene, and toluene ingested by Keith are presented in Table 14. A total of 1.7 mL of the three solvents was ingested. The mixture consists of 73.9% xylene, 20.5% eththylbenzene, and 5.52% toluene. It is likely that these three solvents came from the same source, which is a technical grade xylene that contains about 80% xylenes, about 20% ethylebenzene, as well as small quantity of toluene [13, 16].

Table 11. Keith's tissues and body burden of xylene at the time of autopsy (estimated)

Organ/tissue	Concentration (μg Xylene/g Tissue)	Organ Or tissue Weight (kg)	Total Xylene (mg)/organ
Dry Blood	1.4	4.61	4.5
Brain	20	0.55	11.0
Liver	10	1.30	13.0
Kidneys	2.1	0.26	0.55
Muscles	10	26.4	260
Fat	20	13.18	264
Skin, bone, and others	10.7	19.6	210
Total body		65.9	763

Table 12. Keith's tissues and body burden of ethylbenzene (EB) at the time of autopsy (estimated)

Organ/tissue	Concentration (μg EB/g Tissue)	Organ Or tissue Weight (kg)	Total EB (mg)/organ
Dry Blood	0.8	4.61	1.8
Brain	6.6	0.55	3.6
Liver	2.0	1.30	2.6
Kidneys	0.7	0.26	0.2
Muscles	4.7	26.4	124
Fat	6.6	13.18	87
Skin, bone, and others	2.6	19.6	51
Total body		65.9	270

Table 13. Keith's tissues and body burden of Toluene (Tol) at the time of autopsy (estimated)

Organ/tissue	Concentration (μg Tol/g Tissue)	Organ Or tissue Weight (kg)	Total Tol. (mg)/organ
Dry Blood	0.8	4.61	1.8
Brain	1.9	0.55	1.0
Liver	1.6	1.30	2.0
Kidneys	0.4	0.26	0.1
Muscles	1.2	26.4	31.7
Fat	1.9	13.18	25.0
Skin, bone, and others tissues	0.8	19.6	15.7
Total body		65.9	77

Table 14. The estimated ingested doses of xylene, ethylbenzene, and toluene in Keith's case

Measurements	Xylene	E. benzene	Toluene
Estimated body burden (g)	0.763	0.270	0.077
Estimated % of the dose exhaled	30	10	5
Estimated g ingested	1.09	0.30	0.081
Density (g/mL)	0.865	0.867	0.866
Estimated mL ingested	1.26	0.35	0.094

III-E. Compositions of the mixture of solvents likely ingested by Keith and sources

It is estimated that Keith ingested about 91 mL of mixture and the likely composition of this mixture is presented in Table 15. It consists of 98% organochlorine solvents and

about 2% xylenes mixed with ethylbenzene and toluene. Technical grade xylenes usually contain about 80% xylenes, 20% ethylebenzene, as well as a small quantity of toluene [13, 16]. The xylenes in Keith's case consists of 73.9% xylenes, 20.5% ethylbenzene, 5.52% toluene.

The estimated volume of the organochorine solvents in the mixture is 89 mL, which consists of 79.5% 1, 1, 1-Trichloroethane (TCE) and 20.5% 1, 1-Dichloroethane (DCE). Most of the technical grade TCE sold in the USA contains about 94% TCE and 6% stabilizers such as epoxides and amines to prevent dehydrochlorination of TCE and the reaction of TCE with metals [9, 17]. However, no dioxane was present in Keith's blood and tissues.

The U.S. Naval Research Laboratory analyzed technical grade TCE purchased in 1965 from 4 companies. Their analyses showed that one of them contained 65% TCE, 22% dichloroethane, and 0% dioxane. It was purchased from the Octagon Process Company (Table 16). Octagon's TCE has almost similar composition to the organochlorine solvents mixture recovered from Keith's tissues as described above [17].

TCE, DCE, and xylenes are used as paint thinners. In addition, TCE is used as a cleaner for photographic film (movie/slide/negatives, etc.) and DCE is used as an anesthetic in the past. Some of the common past and present uses of TCE, DCE, and xylenes are listed in Table 17.

Table 15. Estimated doses of solvents ingested in Keith's case and as % of total ingested

Solvents	Ingested Dose (mL)	As % of The dose
1, 1, 1, Trichloroethane (TCE)	70.85	78.0
1, 1 Dichloroethane (DCE)	18.28	20.1
Total TCE & DCE	89.13	98.1
Xylenes (Xy)	1.26	1.4
Ethylbenzene (EB)	0.35	0.4
Toluene (Tol.)	0.09	0.1
Total Xy, EB, and Tol.	1.70	1.9

*Total mL of solvent mixture ingested = 90.83

Table 16. Compositions of four technical grade 1, 1, 1-Trichloroethane (TCE) sold in the USA in 1965 [17]

Sources	% TCE	% 1, 2-dichloroethane	% 1,4-dioxane
Octagon Process Company	65	22	0
Fisher Chemical Company	94	2.1	3.6
Phillips-Jacobs Chemical Co.	95.5	0.8	3.4
Eastman-Kodak Company	95.0	Trace	4.5

Table 17. Some of the past and present uses of 1, 1, 1-Trichloroethane (TCE), 1, 1-Dichloroethane (DCE), and Xylenes*

Solvents	Uses
TCE	• Vapor degreasing of metal products and cleaning precision instruments. • Solvents and carriers for many of active ingredients used in aerosols. • Textile processing and dyeing. • Cleaner for photographic film (movie/slide/negatives, etc.). wkp • Solvents for paints and inks. • Thinner in correction fluid. • Post-harvest fumigation of strawberries. • In the past used as surgical inhalation anesthetic.
DCE	• Feedstock in the chemical synthesis of 1, 1, 1-Trichloroethane • Solvent for plastics, oils and fats, and as degreaser. • In the past used as surgical inhalation anesthetic.
Xylenes	• Solvent in the printing, rubber, and leather industries. • A thinner for paint and in varnishes.

* References [7, 16, 18, 19, 20].

Section IV. Medical evidence indicating Keith ingested a lethal dose of solvents mixed with alcohol within 1-2 hours prior to his death

The pathology and the toxicology data described in Sections II & III of this report reveal that 1) Keith died as a result of receiving a lethal dose of 1, 1, 1-Trichloroethane (TCE) and a toxic dose of 1, 1-Dichloroethane (DCE) via ingestion at about 1-2 hours prior to his death. It is likely that these chemicals were mixed with alcoholic drinks and given to Keith; 2) Keith was exposed to xylene, ethylbenzene, and toluene via ingestion prior to his death; 3) Keith was not exposed to TCE, DCE, xylene, ethylbenzene, or toluene acutely or chronically via inhalation or a dermal route; 4) the source of TCE and DCE was a technical grade TCE; and 5) the source of xylene, ethylbenzene, and toluene was a technical grade xylene. Below is a brief summary of the medical evidence.

1) The following toxicological data and observations show that Keith died as result of receiving a lethal dose of TCE and a toxic dose of DCE via ingestion at about 1-2 hours prior to his death and it is likely that these chemicals were mixed with alcohol.

a) The high concentrations of TCE and DCE in Keith's tissues indicate that he was exposed to a lethal dose of TCE and a toxic dose of DCE acutely prior to his death. The presence of TCE in the blood of an individual at a concentration above 1.0 to 1.5 mg/dL is considered as a lethal level [6]. The concentration of TCE in Keith's dry blood was 6 mg/dL. The estimated dose of TCE and DCE received in Keith's case was 116 g, which is a lethal dose (Table 18). TCE and DCE cause central nervous system (CNS) depression and they have anesthetic effects.

b) The distribution pattern of TCE and DCE in Keith's tissues indicates that Keith was exposed to these solvents acutely prior to his death. The distributions of these solvents in Keith's tissues were influenced by their doses and solubility in lipids. The brain has the

highest concentrations of solvents relative to the blood because of their high solubility in lipids as shown in Table 18.

c) The concentrations of TCE and DEC in Keith's liver relative to the blood were 2.67 and 6.29, respectively (Table 18). The high concentrations of TCE and DCE in Keith's liver relative to the blood indicate that Keith received these chemicals via ingestion prior to his death. These chemicals were absorbed via the gastrointestinal mucosa and reached the liver via portal circulation. The concentration of DCE in Keith's liver relative to the blood is 2.35 folds higher than those of TCE, which indicate that their uptake was influenced by the ingested dose.

d) The ingestion of high doses of TCE and DCE cause irritation of the gastrointestinal tract (GI) and leads to vomiting. The absorption of TCE and DCE through the gastrointestinal tract (GI) produces central nervous system (CNS) depression proportional to the amount absorbed. Vomiting and CNS depression lead to the aspiration of materials present in the GI to the lungs. The microscopic examination of H & E stained sections of the trachea and the larynx showed the presence of aspirated materials (Section II).

Furthermore, 90% of the ingested TCE and DCE are eliminated from the body via lungs. The elimination of toxic levels of these chemicals via lungs causes congestion and edema. The examination of H & E stained sections of Keith's lung showed congestion and edema (Section II-C). These observations also indicate that Keith ingested high doses of TCE and DCE chemicals during 1-2 hours prior to his death.

e) The high concentrations of TCE and DCE in Keith's tissues and their low solubility in water indicate that these chemicals were likely mixed with alcoholic drinks and given to Keith. TCE and DCE are slightly soluble in water (0.4-0.5 g/dL) and very soluble in

alcohol and organic solvents (Table 5). The estimated dose of TCE and DCE received in Keith's case was 116 g. It would require more than 23 liters of water to completely dissolve 116 g of TCE and DCE, which makes water alone, an unlikely vehicle.

Empty wine cooler bottles were found in the park where Keith was found hanging from a tree [4]. Wine cooler drinks usually contain 4-7% alcohol and are mixed with fruit juices [21]. They can be used as a vehicle to increase the solubility of TCE and DCE in water and mask their taste. Alcohol also increases the rate of absorption of TCE and DCE from the gastrointestinal tract, which explains the presence of high concentrations of these chemicals in Keith's tissues.

2) The concentrations of xylene, ethylbenzene, and toluene in Keith's tissues and their pattern of distribution indicate that Keith was exposed to these chemicals via ingestion prior to his death. Their distribution in tissues is influenced by their doses and solubility in lipids. The brain has the highest concentrations of these compounds relative to blood.

The concentrations of xylene, ethylbenzene, and toluene in Keith's liver relative to the blood indicate that Keith received these chemicals via ingestion (Table 18). These chemicals were absorbed via the gastrointestinal mucosa and reached the liver via portal circulation. These observations also indicate that Keith ingested these chemicals while he was alive.

3) Keith was not exposed to TCE, DCE, xylene, ethylbenzene, or toluene acutely via inhalation as indicated by the following observations:

a) The high concentrations of TCE and DCE in Keith's tissues indicate that it takes several hours of exposure to high levels of TCE and DEC in the air to chief the levels

detected in Keith's tissues, because the pulmonary uptake of the inhaled TCE and DCE is less than 50% and 90% of the absorbed dose exhaled.

d) The autopsy did not show marks on Keith's face to indicate that a device or a mask was used to expose Keith to solvents via inhalation. In addition, TCE, DCE, xylene, ethylbenzene, and toluene cause irritation to the nasal and the respiratory mucosa and induce pain. The autopsy did not show evidence of struggle in Keith's case (Section II).

c) Keith's upper respiratory mucosa did not show evidence of irritation and congestion that indicate he inhaled solvents prior to his death. TCE, DCE, xylene, ethylbenzene, and toluene cause irritation of the mucous membrane and the inhalation of high doses of TCE and DCE is expected to cause congestion and edema of the mucous membrane.

4) The high concentrations of TCE and DCE in Keith's tissues indicate that Keith was not exposed to these chemicals via dermal route. The absorption of these chemicals from the skin is slow and 90% of the absorbed dose is exhaled via the lung.

5) The microscopic examination of Keith's liver and kidney reveals that his organs were normal at the time of his death, which indicates that he was not exposed chronically to toxic levels of solvents via inhalation or any other routes (Section II). The chronic exposure to toxic levels of TCE, DCE, xylene, ethylbenzene, and toluene have known to cause liver and kidney problems.

6) The estimated volume of the TCE and DCE mixture ingested in Keith's case is 89 mL, which consists of 79.5% TCE and 20.5% DCE. The U.S. Naval Research Laboratory analyzed technical grade TCE purchased in 1965 from 4 companies. Their analyses showed that one of them contained 65% TCE, 22% dichloroethane, and 0% dioxane. It was purchased from Octagon Process Company (Table 16). Octagon's technical grade

TCE has a similar composition to the organochlorine solvents mixture recovered from Keith's tissues.

Most of the technical grade TCE sold in the USA contains about 94% TCE and 6% stabilizers such as epoxides and amines to prevent dehydrochlorination of TCE and the reaction of TCE with metals [9, 17]. However, no dioxane was present in Keith's blood and tissues. These data indicate that TCE used in Keith's case was not purchased to clean metals and it was likely used as a cleaner for photographic film [20].

Keith's mother found a plain vanilla envelope inside the screen door of her house on April 9, 1992, which is about 6 years after Keith's death. It contained 5 crime-scene photos showing Keith was hanging from a tree. The police department conceded that they were copies of original police photos, but they had no idea where they came from. The original photos were not shared with Keith's mother in 1986 [3, 4].

It is possible that there is a link between the individual who produced a copy of the crime-scene photos and the individual who purchased the TCE used in Keith's case. TCE is used as cleaner for photographic film [20].

7) The estimated volume of xylene, ethylbenzene, and toluene mixture ingested by Keith was 1.7 mL. It consists of 73.9% xylenes, 20.5% eththylbenzene, 5.52% toluene, which is similar to the composition of the technical grade xylene that contain about 80% xylenes, 20% ethylebenzene as well as a small quantity of toluene [14, 16]. It is possible that the technical grade TCE used in Keith's case also contains 2% technical xylene or the technical grade xylene was added to TCE to enhance their solubility in water. Xylene is also used as a solvent in the printing industry.

Table 18. The estimated doses of solvents ingested and their pattern of distribution in Keith's tissues

Measurements	TCE	DCE	Xylene	E. Benzene	Toluene
Part.Coeffic. Log K_{ow}	2.49	1.79	3.12-3.20	3.15	2.69
Ingested Dose (g)	94.94	21.48	1.09	0.30	0.08
Ingested Dose (mL)	70.85	18.28	1.26	0.35	0.09
Dry blood (µg/g)	60	14	1.4	0.8	0.8
Liquid Blood (µg/g)*	30	7	0.7	0.4	0.4
Brain (µg/g)	310	88	20	6.6	1.9
Liver (µg/g)	80	44	10	2.0	1.6
Kidneys (µg/g)	83	22	2.1	0.7	0.4
Muscles (µg/g)	130	32	10	4.7	1.2
Brain/L. Blood	10.33	12.57	28.6	16.5	4.8
Liver/L. Blood	2.67	6.29	14.3	5.0	4.0
Kidneys/L. Blood	2.76	3.14	3.0	1.8	1.0
Muscles/L. Blood	4.33	4.57	14.3	11.8	3.0

* Concentration in liquid blood = concentration in dry blood/2

Section V. Medical evidence indicating Keith's hanging occurred after death and the investigation conducted in 1986 was inadequate

Autopsy studies of suicide hanging cases have shown injuries to the neck soft tissues, bone, and organs in the majority of the cases and bleeding in the soft tissues of the neck in all cases as described in Section V-A. The autopsy showed no hemorrhages, soft tissue injury, dislocation or fractures in Keith's neck. In addition, Keith's tongue, larynx, laryngeal cartilages, hyoid bone as well as his cervical vertebral column visually were without injuries other than some autolytic changes (Section II-B).

The lack of bleeding and injury in Keith's neck can be explained by the following medical evidence: 1) Keith died as a result of ingesting a lethal dose of organochlorine solvents (1, 1, 1-Trichloroethanol and 1, 1-Dichloroethanol) as described in Sections III and IV of this report; 2) Keith's body was lifted and put in a hanging position a few hours after death when the muscles of the neck became stiff due to rigor mortis.

The police and the county medical examiner missed the cause of death in Keith's case because they did not conduct the required standard medical legal investigation in this case as described in Section V-B. Briefly; 1) the police did not take fingerprints from the knot on Keith's neck and the portion of the ropes tied to the base of the big tree to see if other individual(s) tied these ropes.

2) No autopsy was conducted or blood and tissues samples were taken to perform toxicological analyses to rule out other cause(s) of death.

3) Keith's body was sent to a funeral home and his body was embalmed prior to allowing his mother to view the body. In 1992, Keith's mother received 5 crime-scene photos showing Keith was hanging from a tree. She noticed that Keith was wearing clothes other than his own, which indicates that key information for the investigation was missed [3].

It is likely that Keith's body was washed after death and his clothes were changed because they became dirty with vomit and possibly with fecal materials. Keith ingested a lethal dose of organochlorine solvents mixed with alcohol, which caused him to vomit as indicated by the presence of aspirated materials in Keith's trachea and the larynx. Intoxication with ingested organochlorine solvents also causes diarrhea. Solvents irritated Keith's gastrointestinal tract mucosa and also caused pulmonary edema and congestion as shown by the microscopic examination of sections of Keith's lung (Section II-C).

V-A. No injuries noted in Keith's neck similar to those observed in hanging victims

Dr. Isidore Mihalakis conducted the autopsy in Keith's case on May 26, 1994 and he did not find hemorrhages, soft tissue injury, dislocation or fractures in Keith's neck. In addition, Keith's tongue, larynx, laryngeal cartilages, hyoid bone as well as his cervical vertebral column visually were without injuries other than some autolytic changes (Section II-B).

Autopsy studies of suicide hanging cases have shown injuries to the neck soft tissues, bone, and organs in the majority of the cases and bleeding in the soft tissues of the neck in all cases [22-29]. For example, Uzün et al. analyzed the autopsy records of 761 hanging cases of suicidal origin. In 364 of these cases suspension was complete and in 397 incomplete. There was no case aged lower than 10 years. Hyperemic lines around the ligature were prominent in 620 of the cases and soft tissue ecchymosis in all cases.

Fractures in the neck organs were also detected in 446 of the cases. In fracture-determined cases, fracture in hyoid bone was seen in 177, in thyroid cartilage in 163, in both hyoid and thyroid in 106. Vertebral fracture was detected in six cases and fractures both in hyoid, thyroid and vertebra was found in four cases [22].

In addition, Nikolić et al. conducted a retrospective autopsy study that included 557 cases of suicidal hanging: 413 men and 144 women, with an average age of 52.4 +/-17.8 years. In 57.3% of them, hyoid-laryngeal fractures were found: 15.1% had only hyoid bone fracture, 26% had only thyroid cartilage fracture and 16.2% had both types of injury at the same time [23].

Furthermore, Suárez-Peñaranda reviewed the autopsy of 228 cases of hanging deaths. A complete standard autopsy was performed for every case. Most cases (75.3%) presented some kind of bone or cartilage fracture. Vascular lesions were also found in some cases: intimal injuries were found in the carotid artery (9.1%), the jugular vein (2.2%), and ruptures of the carotid adventitial layer (21.7%) [24].

In addition, Sharma et al. evaluated the autopsy of 71 cases regarding asphyxia of constriction of neck and in 69% of them the cause of death was hanging. Injury to the sternocleido-mastoid muscle (54%) was the commonest injury to the neck structures. The hyoid bone was fractured in 21% cases, while the thyroid cartilage was fractured in 17% cases [25].

Załuski et al. also analyzed 140 cases of suicidal hanging who had the knot situated on the neck. In 131 corpses 206 intravital reactions were revealed. Descending incidence of the reactions was as follows: petechial subcutaneous facial and palpebre hemorrhages (33.5%), hemorrhages of muscules sternocleidomustoideus (18.4%), hemorrhages within ligature furrow (11.6%), vertebral cervical fracture (0.7%) [26].

V-B. The investigation conducted in 1986 regarding Keith's death was inadequate

Keith's body was discovered hanging from a tree on July 31, 1986 by a girl walking in the park. She called 911 and the rescue personnel arrived on the scene with paramedic Dallas Lipp in charge. Lipp made close observations of the body and determined that Keith was dead [1]. Montgomery County Police Officer Luther Leverette from the Wheaton-Glenmont Police Station responded to the scene and took charge. He put the time of Keith's death as of 1405 on July 30, 1986 [2].

Leverette contacted the medical examiner office and Keith's death was ruled a suicide. Keith's body was sent to Collins Funeral Home in Silver Spring for embalming [3]. Keith's clothes were changed and his body was embalming prior to allowing his mother and relatives to view the body [3, 4].

The toxicology, autopsy, and the pathology findings described in Sections II-IV indicate that Keith died as a result of ingestion of a lethal dose of organochlorine solvents and his body was lifted and put in a hanging position to make it look like a suicide. The police and the medical examiner missed the cause of death in Keith's case because adequate investigations were not conducted. No autopsy was performed or blood and tissues samples were taken to perform toxicological analyses to rule out other cause(s) of death.

In addition, the police did not take fingerprints from the knot on Keith's neck and the portion of the ropes tied to the base of the big tree to identify the individual(s) who made the knot and tied the rope to the tree. Furthermore, Keith's body was sent to Collins Funeral Home in Silver Spring for embalming and his body was embalmed prior to allowing his mother to view the body.

In 1992, Keith's mother received 5 crime-scene photos showing Keith was hanging from a tree. She noticed that Keith was wearing clothes other than his own, which indicates that key information for the investigation was missed [4].

It is likely that Keith's body was washed after death and his clothes were changed because they became dirty with vomit and possibly with fecal materials. Keith ingested a lethal dose of organochlorine solvents mixed with alcohol and that caused him to vomit as indicated by the presence of aspirated materials in Keith's trachea and the larynx. His intoxication with solvents most likely caused diarrhea because it irritated the mucosa of the gastrointestinal tract. It also caused pulmonary edema and congestion as shown by the microscopic examination sections of his lung (Section II-C).

Embalming Keith's body also interfered with the collection of important medical evidence. The contents of the stomach and the intestine were removed. Dr. Mihalakis stated that Keith's viscera were extensively trocared and the stomach contained minimal granular non-recognizable material. Therefore, at the time of autopsy, it was not possible to take samples from the stomach and the rest of the gastrointestinal tract to do toxicological analysis.

The toxicological evidence indicates that Keith was given alcoholic drinks containing a lethal dose of organochlorine solvents and other solvents. Analyses of the gastrointestinal contents for alcohol and organic solvents can provide very important information in this case. Dr. Isidore Mihalakis also stated thats "the scene investigation and the handling of the body immediately afterward, based on my previous communiqué was inappropriate and not in accordance with accepted standards of a good medical-legal investigation system".

Section VI. Conclusions

On July 31, 1986, Keith Warren was found hanging from a small tree in a park behind his house in Silver Spring, Maryland. Keith's death was ruled a suicide by the police and the county medical examiner and his body sent to Collins Funeral Home in Silver Spring for embalming without performing an autopsy.

Suspicious events had led the family to exhume Keith's body on May 24, 1994 and to arrange for autopsy. Dr. Isidore Mihalakis performed the autopsy of Keith's body on May 26, 1994. High levels of 1, 1, 1-Trichloroethane (TCE) and 1, 1-Dichloroethane (DCE) were found in Keith's blood, brain, liver, kidney, and muscles and these organochlorine solvents are not normal constituents of embalming fluids or decompositional effect. Dr. Mihalakis stated that the cause of death was undetermined because toxicologic findings are incompatible with the autopsy findings.

He also stated that "the scene investigation and the handling of the body immediately afterward, based on my previous communiqué was inappropriate and not in accordance with accepted standards of a good medical-legal investigation system". I evaluated Keith's autopsy and toxicology reports and the pertinent documents and articles cited in this report using differential diagnosis. My investigation in this case reveals the following:

1) Keith had a lethal level of TCE and a toxic level of DCE in his blood, brain, liver, kidney, and muscles. The concentrations and the pattern of TCE and DCE distribution in tissues indicate that Keith received these chemicals at about 1-2 hours prior to his death via ingestion and they were likely mixed with alcoholic drinks. The estimated ingested doses of TCE and DCE in Keith's case are 94.94 g (70.85 mL) and 21.48 g (18.28 mL), respectively.

2) Xylene, ethylbenzene, and toluene were also detected in Keith's blood and other tissues. The pattern of distribution of these solvents in tissues indicates that Keith

received these chemicals via ingestion while he was a live. The estimated volume of xylene, ethylbenzene, and toluene was likely ingested by Keith is 1.7 mL.

3) The estimated volume of the TCE and DCE mixture ingested in Keith's case is 89 mL, which consists of 79.5% TCE and 20.5% DCE. Most of the technical grade TCE sold in the USA contains about 94% TCE and 6% stabilizers such as epoxides and amines to prevent dehydrochlorination of TCE and the reaction of TCE with metals. However, no dioxane was present in Keith's blood and tissues. These data indicate that TCE used in Keith's case was not purchased to clean metals and it was likely used as cleaner for photographic film.

4) The estimated volume of xylene, ethylbenzene, and toluene mixture ingested by Keith was 1.7 mL. It consists of 73.9% xylenes, 20.5% eththylbenzene, 5.52% toluene, which is similar to the composition of the technical grade xylene. It is possible that the technical grade TCE used in Keith's case also contains 2% technical xylene or the technical grade xylene added to TCE to enhance their solubility in water. Xylene is also used as a solvent in the printing industry.

5) The autopsy showed no hemorrhages, soft tissue injury, dislocation or fractures in Keith's neck. In addition, Keith's tongue, larynx, laryngeal cartilages, hyoid bone as well as his cervical vertebral column visually were without injuries. The lack of bleeding and injury in Keith's neck indicate that Keith's body was lifted and put in a hanging position a few hours after death when the muscles of the neck became stiff due to rigor mortis.

6) The police and the county medical examiner missed the cause of death in Keith's case because they did not conduct the required standard medical-legal investigation in his case.

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