Winner of *The Navigator's* Best Writing Award

Embalming and Chemistry: Till Death Do Us Part
A Historical and Chemical Analysis of Mortuary Science

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1 Abstract

A historical and chemical account of the developments of mortuary science from the Prehistoric Era through the Modern Period is discussed. The chemical progression and cultural impacts of each era and the mortuary practices conducted are analyzed for their progressive and detrimental effect on civilizations throughout history. The early methods of preservation are shown to be motivated for mummification and not that of embalming itself but have been able to provide cadavers which can be studied thousands of years after their burial. In the Middle Ages, the use of preservation was entirely motivated by anatomical study, eventually progressing to the formation of mortuary practice as a science in the late 19th century. By the Modern Period, the continued study and modernization of embalming retains many of the traditions established in the Industrial Era; however, research has been shown for sustainable and safer methods of embalming which are able to consistently preserve cadavers for years at a time.

2 Introduction

The practice of embalming was not conducted for burial until the late 1800s. Prior to this time, preservation was a precursor for other procedures, such as religious beliefs or scholarly pursuits. The Prehistoric Era practiced mummification primarily for the entrance of the deceased to the afterlife. The eldest discovered mummies of the Chinchorro people are an exception as there exists no religious motivation for the mummification methods they conducted. However, for the Egyptian and Ancient Chinese mummies, elaborate rituals for the entrance to an afterlife were completed for each cadaver buried.

In the Common Era, the use of embalming was completed such that dissection could be completed at a later date. While mortuary science was not established, improvements in preservative technology for cadavers progressed and provided decelerated decomposition for several weeks at a time. By the end of the 19th century, bodies were embalmed prior to burial during the Civil War. With the introduction of formaldehyde in 1868, mortuary science had fully introduced itself to modern medical practice.

In the 20th century, regulation and improvements in mortuary science progressed. Unfortunately, to present day, a standard method of embalming does not exist. Nevertheless, extensive research has been conducted such that sustainable procedures and solvents can be used for future embalming. The use of formaldehyde persists to present day; however, active research for replacements or modified formaldehyde are pursued for the aforementioned reason. The historical, chemical, and societal impacts of mortuary science have shaped its progression throughout history. From the Prehistoric Era, the practice of embalming is deeply interconnected with chemistry and anatomy. Major examples of mortuary science, their methods, and their effects are discussed and analyzed from prehistory to present day.

3 Prehistoric Preservation

The practice of artificial mummification and body preservation techniques in ancient civilizations are known to have appeared as early as 7020 BCE [1]. The practice of conserving human cadavers was often motivated by religious practice, such as the existence of an afterlife. Geographically, artificial mummification has been linked to South America, Egypt, and China. During the prehistoric time period, each culture held distinct mortuary practices with materials unique to their climate and anthropological advancements. Not only were the practices of preservation elaborate, they involved intricate chemical processes that may not necessarily have been acknowledged by the civilizations.

3.1 The Ancient Artificial Mummies of the Chinchorro Civilization

On the coasts of modern Northern Chile and Southern Peru, the Chinchorro people are the earliest known society which reflected evidence of artificial mummification [2]. The practice of body preservation appeared to hold no bias or reservation toward a specific socioeconomic class, nor affiliation to a religious belief [2]. Currently, there is evidence of artificial mummification for adults, children, and fetuses of all sexes dating to 7020 BCE until 1110 BCE [3]. Various methods of conservation were utilized, including Complex and Mud-Coated Mummies [3]. Complex mortuary practices consist of Black, Red, and Bandaged Mummies, each with their own respective procedures. Black Mummies (7000-5000 BCE) required evisceration, or removal of the internal organs, along with Red Mummies (4000-3000 BCE). The Black Mummies were named after the thick, black manganese paint finish on the body; unlike the Black, the Red Mummies reflected a unique red ochre paint finish. Bandaged Mummies were treated identically to Red Mummies; however, they were coated in a full-body layer of bandage wrappings, composed of linen material. Unlike the Complex Mummies, Mud-Coated mummification practices (3000-1110 BCE) required the body to be smoked or dried with glowing coals before the body was coated in a layer of mud, approximately 1-2 cm thick, which dried into a natural cement [3]. The Chinchorro people were known for recreating facial features, clothing, and even hair for the cadavers. Found within several

Chinchorro mummy burial pits were objects such as fishing tools, leather pouches with pigments, weapons, and other personal belongings [4, 5]. Artificial mummification continued for the Chinchorro people until approximately 1110 BCE, where it is cited that climate changes in the area resulted in them deserting the coasts and migrating to higher elevations [4].

3.2 Ancient Egyptian Mummies and Culture

In Africa, the Egyptian practices may perhaps be the most identifiable and renowned examples of human mummification. Dating to as early as 4500 BCE, the artificially preserved cadavers were reserved for only those of higher stature in socioeconomic status [6, 7]. Unlike the Chinchorro people, the preservation of bodies was attributed to an afterlife. The practice of mummification was considered a lengthy ritual, taking almost 70 days, and continued regularly until as late as 364 CE [8]. Bodies were dried chemically before the use of tars, oils, and resins were employed to treat the cadavers and prepare for wrappings [9]. These practices were altered with time to exhibit modern and longer lasting embalming effects, to ensure that decomposition would be reduced, leaving the body's image constant with time. For example, during the 26th Dynasty of Egypt (664- 525 BCE) the use of resin and animal fat to secure bandages was more commonly used compared to more traditional, older mummies, which did not utilize these materials [10]. Like the Chinchorro people, the Egyptians often buried items of personal belongings and gifts with the dead, such as gold, weapons, and elaborate coffins which were often painted to represent the identity of its host [8]. It has been shown that the ancient Egyptians continued to mummify bodies until the end of the Roman Period (364 CE) [8]. With the rise of Christianity in Egypt, the practice of mummification was criminalized; as a result, preservation rituals ceased.

3.3 Han Dynasty Mummies in Ancient China

In ancient China, one of the most notable cases of artificial mummification was that of Lady Dai, or Xin Zhui. The body was preserved meticulously - so much so that a complete autopsy could be completed in 1972, over 2,000 years after her death; her remains and the methods of her conservation are actively researched today [11, 12]. Lady Dai lived during the Han Dynasty, (206 BCE - 9 CE) and was considered a noblewoman of her time. Buried alongside her husband, Li Chang, Chancellor of Changsha Kingdom, her body was found submerged 12 meters underground, within four protective coffins and enclosed in a room intended for her immersion to the afterlife [12]. Furthermore, the use of charcoal and a thick ash-paste layer lining of the chamber protected the space from water damage as well as limiting natural oxygen which would further decompose the body. Fascinatingly, her body was submerged in 80 liters of an unknown solution noted to be slightly acidic and containing traces of magnesium [1, 11]. As observed with the Chinchorro and Egyptian mummies, personal items were found within the tomb of Lady Dai, including clothes, valuable items, and even a prepared meal for her to consume once she entered the afterlife. The practice of artificial mummification in ancient China was so sustained that her cause of death, a heart attack, could be determined [12]. While the state of her body is still considered one of the most well-preserved mummies throughout history, it was noted that by removing her corpse to complete the autopsy that her remains began to decompose [11, 12]. It is debated whether or not the acidic solution was prepared intentionally, or if it occurred naturally as her body began to gradually decay. Any other conservation methods to Lady Dai remain unknown, along with similarly preserved bodies found within 200 kilometers of the Zhui family [1]. These remains were also noted to be of elite members of the Han Dynasty, representing the privilege of the sacred practice reserved only for aristocratic members of society.

3.4 Chemical Analysis of the Chinchorro Mummies

Artificial mummification methods and chemical analysis are limited for the aforementioned civilizations due to the lack of documentation from the people themselves, and limited evidence of resources. However, the intention and significance of these materials along with the resulting advancements in mortuary practice that the civilizations achieved are plentiful. Treatment of the bodies in the Chinchorro civilization varied slightly for each type of Complex and Mud-Coated mummy. Black Complex Mummies were conducted by first disarticulating the body by removing the skeletal structure [5]. Treatment with hot coals was completed before a coat of white ash-paste was applied to create facial features; the representative identification was attributed by the final layer of black manganese (cryptomelane) paint on the cadaver after the entire process was completed. The source of the paint is debated, with some sources claiming that the Chinchorro people had traveled to the highlands (90-100 km) to mine cryptomelane naturally, which was then crushed and mixed with animal fats to obtain the shiny black paint they desired [3].

Preceding Black Mummies, the Red Mummies had a very similar process, but were lastly coated with red ochre. The first Red Mummy, found approximately 2800 ± 155 BCE, was found to be almost identical to the Black Mummies; however, it exhibited stripes of red and yellow ochre on their outer mud layer. Official Red Mummification practices were not dated until 4500-4000 BCE. Similar to the Black Mummies, the Red Mummies were coated with white ash-paste to sculpt their facial appearance. Further, black manganese paint was applied, though only on the facial portions, with the final unique detail being that of red ochre painted on the body, or trunk. Studies completed on the paints applied to both the Red and Black Mummies show that the red paints were reapplied several times - either before burial or after multiple exhumations [5]. The pigment composition reflects that the Chinchorro people had developed very specific recipes to obtain a desired paint, such as grinding natural hematite (ferric oxide) before mixing it with clay and animal fat to achieve a distinct red hue [4, 5]. By 3000 BCE, complex mummification had decreased in Chinchorro civilization, and bodies were no longer eviscerated; only dried with coals before being coated in thick layers of mud material. The mud used for the Mud-Coated Mummies often contained traces of sea lion blood, fats, or other proteins. Additionally, binders added to the mud for its stability include sand, fish or egg glues, and "vegetal fiber that could have been intentional inclusions or a result of contact between the cadaver and a mat while the coating was being applied," [3]. In contrast to the Black and Red Mummies, the Mud-Coated Mummies were treated directly next to the burial pit, and not beforehand in a separate location. Similar to the previous mummification processes, the Chinchorro people would be buried with belongings, supplies, fishhooks, spears, and other materials [3, 5].

3.5 Ancient Egyptian Mummification Chemistry

The Egyptian mummification process was far more elaborate than that of the Chinchorro people. The 70-day ritual of preservation, prayer, and study was completed routinely for the aspiration of an intact, unchanged body for the individual's entrance in the afterlife. Their perspective culturally was that death was a pause in their lifespan, which continued thereafter. Similar to the Chinchorro people, the process of Egyptian mummification would begin with evisceration, in which the organs would then be stored in jars or wrapped individually before then being returned to the body [8]. The entire cadaver and interior would then be dried for forty days with natron, composed of a mixture of sodium carbonate (Na_2CO_3), sodium bicarbonate ($NaHCO_3$), sodium chloride (NaCl) and sodium sulfate (Na_2SO_4), which would both disinfect and preserve the skin and internal structure [13]. Once the natron was removed, the body would be filled with straw, soil, or bandages to retain its shape. Afterward, application of juniper or cedar oils and tars, along with animal fats, linens, and even false eyes were used to conserve the body, limit odor from decomposition, and retain its original life-like appearance [8, 9].

The Pyramid of Djoser, also known as the Tomb of Saqqara (approximately 664-525 BCE) contains a connected embalming workshop where jars of embalming materials were stored. Several pottery vessels and clay beakers were found within the workshop, each storing compounds such as beeswax, tar, and mixtures of fats and oils used for the treatment of the liver, perfumes for the body, and treatments for the head [9, 14]. The process of obtaining the tar and animal fats required a thermal extraction, either by smoking or boiling material [9]. Furthermore, the resin applied to the bandages required mixtures of a dense oil (such as cedar), bitumen (natural or petroleum- based asphalt), and beeswax mixed with balms, all of which required heating processes to be completed before use. The oils themselves were dry-distilled from cedar trees, where the wood would be smoked above hot coals and the oil collected [15, 16]. Bitumen, a naturally occurring tar which is commonly referred to as asphalt, was applied and dried into a hard shell around the corpse and preserved the remains. Bitumen, while not distinctly chemically defined, has been shown to contain approximately 85% carbon, with the remaining materials shared between oxygen, hydrogen, nitrogen, and sulfur [17]. The bitumen resin showed evidence of being melted before application, and once cooled, it transitioned to a thick and dark shell over the linen bandages. The tar was obtained from smoldered cedar wood and said to be the most effective preservation material when used to secure bandages [9, 10, 14].

3.6 Ancient Chinese Mummy Methods

While much remains unknown about the mortuary items used for the body of Xin Zhui in ancient China, the materials used for the chamber itself created an environment that protected the body from the effects of nature for over two thousand years. The body was enclosed within four coffins, preserved so immaculately that she retained all body hair, her limbs could still be manipulated, and most importantly, a full autopsy could be performed [11, 12]. It was determined that she had died from congestive heart failure, resulting from poor eating habits and a sedentary lifestyle. Notably, she was found to have over one hundred melon seeds within her stomach - which would have digested within one hour of consumption - implying she had been mummified immediately after her death [9]. She was laid to rest with her husband and another body, presumed to be her son [18]. The coffins themselves, each lacquered and sealed, deprived the body of oxygen and allowed the solution to remain undisturbed [18]. Visually, intricate designs were painted on the surface of the coffins, each depicting the initial rituals she would participate in once she had entered the afterlife. The chamber, which resided 12 meters underground, was lined with over 5000 kilograms of charcoal and one meter of thick white-ash paste, to withhold an almost constant and stable environment [18–20]. The white ash-paste, composed of potassium chloride (potash) would protect the body from humidity; paired with the charcoal, the chamber itself would remain preserved. The chamber entrance was sealed with one meter of clay and packed with soil to the surface. This ensured relatively constant pressure, temperature, and humidity, which created a practically sterile environment [11, 12, 18–20]. The abundance of materials used to create the chamber allowed it to be almost completely isolated from the natural environment, delaying significant decomposition for centuries.

3.7 Impacts of the Chinchorro Civilization

During the periods in which artificial mummification was practiced, the methods themselves were significant both culturally and academically, but are wrought with wasted material and dam- ages to the environment. For the Chinchorro people, the use of buried tools and belongings would have decreased the availability for that of the living population. Prior to their establishment on the coast, the arid Atacama Desert would naturally mummify remains and preserve the dead something the Chinchorro people would have noticed and perhaps wished to continue once the humidity increased in the area, thus accelerating natural decomposition [19]. To gather materials such as cryptomelane for the mummification processes, it may have required people to travel to higher elevations, approximately one hundred kilometers away [5]. While it is debated whether or not these compounds were available on the coasts, their applications being used to preserve the dead can be argued to have wasted potential for other resourceful or practical prospects, such as building homes or more advanced tools.

The Chinchorro people were deliberate and meticulous about their methods of burial, often observed with the refinement of types of mummification and their respective influence on the more modern techniques. Their obtaining and manipulation of materials were elaborate, such as melting, crushing, and mixing certain oxides to obtain specified pigments for paints on the Red Mummies, or the thick cement-like mud on the Mud-Coated Mummies. The process of evisceration on the Black and Red Mummies would allow the practicing people to gain experience in anatomy, the application of paints to promote creativity in painting and art, and the burial to encourage cultural growth. Although there is no official religious practice that is said to have motivated mummification and burial of the Chinchorro people, it is discussed that perhaps with time, religious beliefs may have developed [3].

3.8 Ancient Egyptian Effects

The Egyptian mummification practices varied greatly from the Chinchorro people, the foremost being its religious implications. Their belief in the existence of an afterlife resulted in lengthy and elaborate rituals before, during, and after the mummification and burial processes. Within the tomb of Saqqara, several 'megatombs' were found, with approximately three hundred empty coffins all painted and prepared for bodies, and one hundred occupied sarcophagi [21]. Frequently used in all Egyptian tombs, the use of gold for gilding masks and for precious items - often associated with rulers - are found. These items were buried with their owners, and unavailable for the remaining living population. Furthermore, the burying of statues, tools, and foods would then be limited to the population. The growth of language through art and hieroglyphics were used on the walls and on the coffins; however, the tombs were sealed to prevent looters from stealing the belongings of the deceased. This deliberate prevention of analysis and discovery for the sake of burial prohibited the Egyptian people from using the materials for collective advancement. Furthermore, the lengthy process of prayer and embalming duties would require priests to diligently work on the bodies for months at a time, preventing them from participating in other societal duties that would be more practical and productive for the Egyptian society.

Additionally, much of the Egyptian embalming materials did not appear naturally and would require chemical manipulation to obtain. For example, the balms and resins for sealing the bodies required cedar trees to be dry-distilled or smoked and were even detrimental to the environment. The use of these balms and resins, specifically bitumen, were used for more humid environments - such as within the tombs themselves, to prevent the bodies from decaying at a faster rate. While it has been stated that the bitumen specifically was obtained potentially from the Dead Sea; artificially made bitumen is a petroleum-based asphalt material, requiring heating by burning of fossil fuels. Petroleum-based bitumen is considered extremely flammable in liquid state and can cause significant lung damage, something that was noted to be used on Egyptian mummies [22, 23]. The use of materials that are dangerous to the respiratory system in an enclosed space with limited ventilation could cause tremendous lung deterioration for Egyptian mortuary practitioners.

3.9 Ancient Chinese Cultural Outcomes

For the practices of Lady Dai, the incredible amount of labor contributed to the creation and strengthening of the chamber would require a gargantuan effort to construct, whether that be of time or people. The careful articulation of food preparation and used materials for her preservation and coffin would result in materials being deprived from civilization, much like that of the Egyptian practices. While the Han Dynasty is renowned for its effective leadership and sustained social construct, the misuse of materials for ensuring a stable environment to reside deceased human remains would lack practical use for the living society. Furthermore, the artistic applications for the coffins, the materials within the tomb, would be wasted for future study, cultural, and artistic development.

While the solution in which Lady Dai is preserved is still unknown, the potential for future study on her remains is still active, allowing the opportunity of potentially sustainable preservation methods to be practiced or analyzed. Additionally, the tomb itself being constructed so soundly provides insight into the methods and knowledge of the ancient Chinese people; the use of charcoal and ash-paste to limit water and oxygen to allow for an almost completely unchanged environment. While no documentation has been yet published for the mortuary practices themselves, what has been established provides insight into the intentions for preservation and stabilization of the deceased elite in ancient China.

3.10 Overview of Prehistoric Embalming

While there is much to be discovered about the purposes and practices of artificial mummification prior to the Common Era, what is known gives only a glimpse into the expertise of ancient mortuary science. The ability for remains of individuals from over 3,000 years ago to still be analyzed and preserved could not have been planned by ancient civilizations, though their contributions to modern day practices are indispensable. By providing modern scientists with their examples of complex and uniquely preserved cadavers, ancient civilizations will continue to motivate study of mortuary science and growth for years to come. While the methods of the Prehistoric Era solely surrounded mummification, the progression of embalming in the Common Era provided the resources for mortuary science to be established as a field.

4 Embalming in the Common Era

The history, methods, and outcomes of body preservation from prehistory to present day has attributed tremendously to the development of anatomy and culture. From the complex beginnings of mummification and evisceration to the chemically motivated use of solvents and vascular injections, the historical progression of embalming has not only assisted significantly with anatomical study, but also to the field of chemistry entirely. The motivations of preservation, chemical intricacy, and cultural impact of posthumous practices have been vital to the development of early civilizations and will continue to be studied as modern mortuary science progresses.

4.1 Early European Preservation

Historically, body preservation methods for early civilizations are accredited to mummification. Prior to the common era, this practice was common for a variety of cultural motivations and purposes. For the ancient European civilizations, 'mortuary science' did not fully develop until after the Middle Ages. Prior to this time, in approximately 0-1300 CE, the ancient Greeks and Romans were known to have applied oils and alcohols to bodies to cleanse and preserve them prior to burial. The use of oils was often due to the smell of the cadavers, though both alcohols and oils did not facilitate any long-term preservation [24, 25]. The use of vanillin was common to assist in reducing odor from the body before being encased in a coffin, often lined with lead [26]. By the 13th century, France pioneered mortuary science with the discovery of dissection and anatomy, using oils and alcohols - similar to the Greeks and Romans, but also using salts to dry bodies [27, 28]. The development of anatomy and dissection contributed significantly to the progress of mortuary science and embalming methods as bodies needed to be preserved for at least a week to be studied by students and scholars alike [29]. Additionally, the use of cinnabar, gypsum, and aloe on elite religious figures was completed in the 1300s, such as with Saints and popes [30]. Bodies would be eviscerated with the bones boiled and dried, and fats would be introduced into the body and would harden as a method of preservation [31]. These practices did not ensure long-term preservation but did decelerate the decomposition process for approximately 3-7 days [1].

4.2 Embalming in the Middle Ages and Renaissance

In the Middle Ages, anatomical study in Europe had flourished and the exploration of preservation techniques greatly evolved. Prior to the 14th century, embalming methods were limited to washing the body before burial. In the early 1500s, anatomical study flourished in Europe, particularly in France and Italy, and universities began to offer courses for scholars to study the dissection of the human body. In Brittany, France, bodies were mummified and buried from the 16th-18th centuries. These bodies, once exhumed, were stored in wooden or lead coffins and their organs were encased in lead containers. The hearts were enclosed in representative heart-shaped lead cases which were engraved with the name and dates of the person that they belonged to [25]. In Italy and France, famous artist Leonardo da Vinci (1452-1519) is known to have studied anatomy by injecting waxes, inks, and oils into over 30 cadavers to observe the preservative effects over time [30, 32, 33]. Da Vinci was far more experimental than some of his peers; his practices, "... including washing organs with running water, injecting wax into the ventricles of the brain and blood vessels, cutting bones and organs. When embalming, he conducted experiments with various solutions: turpentine, lavender oil, rosin, camphor, potassium and sodium nitrates" [32]. Unfortunately, the gargantuan increase in grave-robbing related crimes caused the frequency of anatomical study to be limited, as successful attempts to preserve bodies for periods longer than one month were not achieved [33]. During the Crusades, the practice of boiling corpses in a mixture of salt water, aromatic herbs, and natural antiseptics was used to "... dismember the corpse and facilitate the storage and transportation of the relics to the places of burial," [27]. Major contributors to the study of embalming are accredited to Peter Forestus (1522-1597) and Ambroise Pare´ (1510-1590), both of which who studied the use of "aqua vitae", a solution of dilute ethanol, and the forefront of vascular injections to preserve bodies for longer periods of time [32, 34].

By the 18th century, anatomical study had continued to progress to more exploratory methods, especially motivated by the studies of da Vinci. His practice of injecting liquid wax into the vascular structure of bodies motivated several other scientists to explore other substances. The use of vascular injections is not considered to officially debut until the mid-1700s, pioneered by Dr. Frederik Ruysch (1683-1781) [1, 27]. While da Vinci pioneered the use of inks, oils, and waxes, Ruysch explored a solution of 'liquor balsamicum', which "... contained clotted pig's blood, Berlin blue and mercury oxide," [1]. His methods were so perfected that Peter the Great was said to have been convinced bodies were still living after the embalming process was complete [35]. Further contributions by Jan Swammerdam (1637-

1680) used a mixture of "... alcohol, turpentine, wine, rum, spirits of wine, and colored waxes..." to retain life-like appearance of animals and insects [34].

It was noted that Ruysch practiced Swammerdam's methods on Admiral Sir William Berkley, who died at sea in Holland and was preserved to return to England for burial with great success, showing the growth in collaboration and practice of shared mortuary science methods [34]. By the end of the 17th century, methods included using alcohols, salts, turpentine, potassium carbonate, and ammonium chloride to preserve bodies for several weeks at a time [1]. Another major contributor to the progression of mortuary science is that of Jean Nicolas Gannal (1721–1783), who used a mixture of acetic, nitric, and hydrochloric acids as well as various salts of copper, mercury, and sodium for the treatment of cadavers [1]. Most successful for his practice when compared to that of his predecessors was the use of aluminum acetate, which would successfully preserve the corpse without lacerating it. This non-invasive method was so precise and mastered that a cadaver could be preserved 60-90 days without decomposition [35]. Many mortuary practitioners were also accredited to submerging the body completely in alcohol solution or in mercury (II) chloride solution [1]. The use of metals like zinc and mercury on corpses allowed them to be preserved for longer periods of time for burial or anatomical practices, which were studied fervently during this time.

By the late 18th century, several figures emerged for their successful and documented practice of mortuary science. In France and Italy specifically, the use of mercury dichloride, arsenic, and zinc chloride by Georges Cuvier (1769-1832), Franc¸ois Chaussier (1746-1823), and Louis- Jacques Thenard (1777-1857) was shown to have great success [1, 28]. Additionally, the Flemish and German regions of Europe were known to have practiced embalming methods with religious motivations during this time, where bodies would have, "Small incisions or holes were made in the body to facilitate the penetration of the liquor, which usually consisted of a distillation of alkaline solutions (such as brine, but sometimes also caustic lime and vinegar) with wine spirits, turpentine, or sulphur, and various spices," [27]. During the Napoleonic Wars, French surgeons practiced wax injections into cadavers with inks to preserve natural colors of the skin for burial. Furthermore, they practiced, "... such beauty treatments as the application of hair dye, the insertion of glass eyes, and the use of paints to tint the skin, in order to give the body the appearance of intra vitam ['dur- ing life']," [27]. It was often practiced to soak bodies in arsenic or alcohol prior to the injections to cleanse and preserve as well as prevent bacteria from inhibiting the corpse and from spreading disease.

4.3 Civil War and Mortuary Science

During the Civil War, arsenic was commonly used as it prevented disease from spreading to the living; however, there required new methods to preserve bodies for longer periods of time such that they be returned to their homes for burial. Prior to this time, the use of embalming techniques was mostly motivated for dissection or used after dissection was completed, and embalming done solely for the purpose for burial was not common. A major early documented case of embalming solely for burial would be that of President Abraham Lincoln's son, Willie, who had passed from Typhoid fever in 1862. It was one Henry P. Cattell who agreed to embalm the body for burial [36]. His methods were so perfected that Willie remained life-like; it was said President Lincoln requested his son's coffin be reopened multiple times as he appeared as if he were sleeping [34, 36]. It was the same Henry Cattell who embalmed President Lincoln himself, and in both cases, "Using a French embalming mixture described by the Chicago Tribune on May 2, 1865 as 'a concentrated solution of sulphate alumina,' the doctors were able to "make the body like marble' so that it would 'not perceptibly change for several months' and would 'never know decay,'" [37]. During the height of the Civil War, surgeons Dr. Richard Burr and Thomas Holmes explored methods of preservation by using zinc chloride and lime [1, 38]. Both Burr and Holmes initially started preservation methods for families that wished to have the bodies returned for burial, in which they would charge approximately 100 dollars per corpse for preservation. The use of sawdust was also common to ensure the bodies were preserved and dried, though injection of zinc chloride was most directly used. The preservative methods of Burr and Holmes established the use of mortuary science as a preparatory burial procedure, and no longer a precursor for anatomical study or religious motivation.

By 1859, Aleksandr Butlerov had discovered formaldehyde, though it was not used for embalming practice until 1868 by Wilhelm von Hofmann, which immediately was noticed by morticians for its long lasting effects on cadavers: upwards of over one year of retaining a preserved state [1]. Soon thereafter, "Phenol was introduced to anatomical embalming by [Fredrick William] Laskowski (1886) in the mid-19th century. He initially used a mixture of phenol and glycerine as vehicle (one part phenol, 20 parts glycerine); later on, he replaced parts of the glycerine with alcohol (one part phenol, one part boric acid, four parts alcohol, 20 parts glycerine)," [1]. Both methods were used often for the preservation of corpses due to their long-lasting effects and repetitive results. Both methods are still used today; however, they were soon found to have negative effects to the human body, with formaldehyde being the worst, "In addition, the immediate adverse effects were already known: skin irritation, conjunctivitis, irritations of the respiratory system, and headache," [1]. Phenol has been argued to be more detrimental to health; however, formaldehyde has been shown to have greater debilitating effects for short term exposure [39]. Nevertheless, current research for the replacement of both solvents has been undergoing since their introduction [1, 39].

4.4 Ancient European Embalming Properties

While at the foundations of the common era, the use of resins, oils, and alcohols are not necessarily chemically motivated, the increase in chemical complexity of modern embalming practices requires explanation as to the motivations and abilities of the materials. In approximately 250- 1000 CE, the use of vanillin, or vanillic aldehyde, is modernly considered a "green embalming fluid" [1]. The use of vanillin for cadavers would delay decomposition for approximately 3-7 days, allotting enough time for dissection and anatomical study. Furthermore, lead coffins were common for French embalming practices, which would both prevent decomposition from moisture in the environment as well as limit the odor from the body itself. By encasing the organs of the bodies, often embalmed themselves, their decomposition could be decelerated for centuries [25]. In the 16th century, the use of alcohol solutions was common to cleanse bodies prior to burial. More specifically, ethanol was used as well as natural wines and liquors to cleanse and dry cadavers; these substances were both antiseptic as well as preservative.

4.5 Middle Ages and Renaissance Chemical Developments

For vascular injections, the use of waxes and inks were most commonly used by da Vinci and Ruysch. For Ruysch specifically, the use of clotted pig's blood, Berlin blue, and mercury oxide were used [1]. Berlin blue, also known as Prussian blue, when reacted with mercury oxide, yields the following reaction,

$$6C_{18}Fe_7N_{18} + 54HgO + O_2 \rightarrow 54Hg(CN)_2 + 14Fe_3O_4$$

The product, mercury (II) cyanide, is known to be an antiseptic but is toxic as it contains mercury, combined with clotted pig's blood may have allowed it to solidify within the vascular system of the cadaver over time. Additionally, the use of cinnabar and gypsum, also known as mercury (II) sulfide and calcium sulfate dihydrate respectively, were used specifically for their cleansing and dehydrating properties.

Alcoholic solutions were common in the late 1600s for their antiseptic properties as well as their ability to mask smells. For the practices of Swammerdam, mixing of alcohols and turpentine to preserve corpses would result in an extremely flammable fluid but would also cleanse the body before introducing waxes. Turpentine, obtained from resins in coniferous trees, may also have been used as a perfume due to its pungent odor. Ethanol in the form of alcohol spirits (wine, rum, etc.) was also often used; however, their preservative abilities were limited to approximately 3-7 days, similar to that of vanillin [1]. The use of mercury (II) chloride was similar as it would react with bacteria in the body to produce methyl mercury, chemically cleansing the corpse as it remained in the body. The early chemical knowledge of the antiseptic properties of these substances was known at this time, and it was often that these materials were used medicinally before their toxic effects were known, such as with mercury (II) chloride and mercury oxide. During the 1700s, arsenic was mainly used for its ability to eat away bacteria which created the odor affiliated with corpses, but unfortunately persisted without decomposition in its extremely toxic elemental form. In France and Italy, arsenic was used as well as alcohols and chloride solutions, such as mercury and zinc [1, 28]. The mixtures of heavy metals with arsenic could prove toxic in air, water, and food for scholars as both mercury and arsenic have been shown to be carcinogenic [40].

4.6 Industrial Era Embalming Practices

By the 1800s, both phenol and formaldehyde were widely used for their ability to preserve bodies much longer than that of previous materials. Phenol, also known as benzenol, is mildly acidic and can irritate the skin. Its use was quickly limited due to its acidic properties, which could injure morticians during practice; however, its formaldehyde counterpart was known as a respiratory irritant and caused debilitating effects within 15 minutes of exposure [1]. Studies completed on the concentration of phenol used in embalming practices have been shown to have little effects on the morticians' respiratory tract, and that conversely, formaldehyde is shown to have significant risk of respiratory damage when used for embalming [39, 41]. The use of phenol was not only for its antiseptic properties, but also for its ability to cauterize wounds, "The standardized use of phenol as a wound cleanser just missed the Civil War and it is interesting to speculate on the effect that phenol would have had on battlefield casualties," [42]. The significance of carcinogenic properties of solvents used for embalmers during this time may not have been thoroughly researched but could have posed health risks which were unknown at the time. While formaldehyde was almost immediately noticed for damaging health effects, phenol was often attributed to having skin irritant risks for mortuary scientists, which were only shown for prolonged exposure due to its mild acidity [42]. Formaldehyde, however, was shown to have caused respiratory issues such as asthma and more recently, known to be carcinogenic [41].

In 1886, the use of phenol and glycerine was used for anatomical embalming by Fredrick William Laskowski. This reaction causes phenol to diffuse at a much slower rate, which would continuously limit bacteria growth over time [43]. This reaction was changed to a mixture of phenol, boric acid, alcohol, and glycerine, which would increase the antiseptic properties via the mixture of boric acid with alcohol. This reaction paired with the decelerated diffusion of phenol would result in bodies which could be preserved and sterile for periods greater than 6 months. However, formaldehyde is still used in modern mortuary science, although biodegradable and non- carcinogenic substances are actively being researched

[1, 39]. For the preservation of President Lincoln and his son Willie by Henry Cattell, his use of aluminum sulfate would result in the body representing a marble-like appearance [37]. Aluminium sulfate coagulates rapidly in water, which would result in a solidified cadaver after this reaction has completed, "When dissolved in a large amount of neutral or slightly alkaline water, aluminium sulfate hydrolyzes to form the aluminium hydroxide precipitate $Al(OH)_3$ and a dilute sulfuric acid," [44, 45]. The reaction between aluminium sulfate and water is shown below. Unfortunately, the produced sulfuric acid from the reaction poses irritant risk for embalmers and cadavers alike in the case of spills or reactions within the body [46].

$$Al_2(SO_4)_3 + 6H_2O \rightarrow 2Al(OH)_3 + 3H_2SO_4$$

4.7 Early European Impacts

Mortuary study throughout history did not necessarily create positive outcomes. Prior to the Middle Ages, the use of embalming was often done with religious motivation to preserve the body or honor it in some way. For the practice of preservation for Italian Saints and other religious elites, the use of materials and study for the bodies was influential as it encouraged cultural growth and anatomical study. On the contrary, the French practice of storing bodies and organs in lead containers could put embalming practitioners at risk of lead poisoning as there were hundreds of bodies preserved with these methods [25, 26]. With the introduction of anatomical study, the motivations for embalming practice were not motivated by religious affiliation, but more so that of study itself. Bodies obtained in early anatomical study were most commonly from capital punishment and male. Unfortunately, the resulting crimes committed by anatomical scholars for acquiring cadavers resulted in a negative connotation for the practice. For example, it was common for graves to be looted for corpses, especially female ones, and as such required laws to be set forth for fines to any parties found guilty of looting [29, 33].

4.8 Effects of the Middle Ages and Renaissance Eras

While the increase in anatomical study was educationally progressive, there were cases in which it was not motivated by study: in Italy, a body was donated for anatomical study but was soon after discovered to have been murdered by the individual who donated it, resulting in their capital punishment for the homicide and disposal of evidence [33]. The unfortunate purpose of this action was the belief that by donating bodies for study that they would be disposed of conveniently, which was certainly not the case. Criminal acts of anatomical researchers were also a prominent issue in embalming practice during the Middle Ages. Scholar Andreas Vesalius (1514-1564) and his students were known to have "... lack of respect for persons and his candid pride in the acts of daring and deception required to obtain what he considered an adequate supply of cadavers. He and his students forged keys, rifled tombs and gibbets, and stole in and out of ossuaries," [33]. These actions motivated fines to be set forth and regulations on the bodies received as many civilians were concerned for the risk of being buried or dissected whilst still alive. During the 1600s, toxic metals such as mercury and lead were increasingly used, which may have resulted in detrimental health effects due to their toxicity in air, water, and soil. Additionally, the lack of knowledge on the bacteria within the corpses (especially those which had been illegally exhumed) could have put risk of disease if practices were not completed thoroughly. Nevertheless, the mortuary studies completed in the Middle Ages and Renaissance provided gargantuan medical and anatomical knowledge, allowing great advances to be made in medicine which could not have been known without the study of the human body. Furthermore, the evolution in preservative solutions and vascular injections provided methods for embalming and burial and established primitive mortuary science which further developed in the 19th century.

4.9 Industrial Era Outcomes and Impact on Modern Mortuary Science

During the Civil War, the use of embalming practice was influential as it permitted many families the closure of mourning where their lost relatives could be returned to a life-like state. The ability to preserve bodies for longer periods by that of Cattell, Burr, and Holmes shaped the entire mortuary science and separated it from anatomical study. By doing so, the scientific progression of preservation itself was able to be explored and documented [37, 38]. Unfortunately, the use of formaldehyde and phenol has created much debate on their irritating properties for embalming practitioners and cadavers in modern embalming practice but have permitted the ability for corpses to be preserved for several years. By introducing these solvents, the field of mortuary science can continue to explore better preservation methods able to withstand decomposition while retaining sustainable composition.

4.10 Overview of the Early Common Era and Embalming

From the beginning of the Common Era to the modern practices, mortuary science was not officially known until the latter half of the 19th century. While the motivations for embalming methods vary, the practice itself withstands time as a way to preserve life for cultural significance and educational growth. The use of formaldehyde completely changed the process of embalming and motivated the practice of mortuary science in the Modern Era; however, its detrimental effects quickly motivated research for sustainable and preservative solvents that retained the health of both morticians and cadavers alike. Not only did anatomical study and early Common Era embalming enable to exploration of anatomical knowledge and assist in the field of medicinal practice, it also embodies an entire branch of chemistry which explores the ability and longevity of decelerated decomposition, which has continuously been studied through the Modern Period to present day.

5 Mortuary Science in the Modern Era

The development and progression of modern embalming methods from the year 1900 to present day have shaped the cultural and scientific studies of mortuary science and embalming chemistry. Current preservation methods, while complex, are deeply interconnected with the procedures of the late 19th century. The chemical advancements of modern embalming processes encourage the production of new solutions and practices which optimize sanitation, restoration, and preservation of cadavers. The cultural, chemical, and environmental impacts of modern embalming are equally significant to its history, present study, and the future.

5.1 Mortuary History in the Early 20th Century

With the introduction of phenol and formaldehyde in the late 1800s, their applications in embalming science were unprecedented for their ability to sterilize and preserve cadavers for months to years at a time [1, 47, 48]. Unfortunately, the availability of embalming for civilizations was initially offered only in the United States, whereas in Europe, preservation was reserved for elite members of society until the mid-late 1950s [1, 49]. After the Civil War, it became necessary and common for bodies to be treated prior to burial. With the progression of embalming during the Industrial Revolution, the practice became a commonplace for 20th century America. Coffins were typically made out of wood, though the use of pre-made coffins were met with controversy in the early 1900s America. Construction of coffins for cadavers was completed with necessity as coffin-makers were entirely separate from mortuary practice [48]. As time progressed, modern morticians gained responsibilities for the preservation of the corpse, preparation of funeral items (i.e. service, coffin, burial), as well as carrying out the wishes of the relatives for each unique case. Education for embalmers was by certification simply by the completion of a few courses, and licenses were not fully required across the United States until the 1930s [48]. By the 1930s, state Funeral Director and Embalmers Laws were established, ensuring that mortuary practices were conducted only by licensed officials [50].

The use of formaldehyde surpassed that of arsenic in the late 19th century, not only for its preservation ability, but also due to criminal activity. Multiple homicides from arsenic poisoning, which were often falsely attributed to the embalming fluids used at the time, motivated the cessation of arsenic as an embalming fluid [51]. By the 1910s, the use of arsenic-based embalming solvents was federally banned in the United States due to the ability for arsenic to transport in groundwater and cause contamination alongside its elusive properties for criminal investigations [52]. During this time, the production of embalming solvent companies began to emerge, such as The Hill Fluid Company, presently known as The Champion Company, which became the first to publish an encyclopedia of mortuary science research [53]. Solvents introduced by the Hill Fluid Company included that of cavity fluids, vascular fluids, and topical solutions, each with specific purposes for the treatment of the cadaver. The primarily practiced method of preservation for the 20th century is described as follows [48, 54, 55]:

1. **Arterial Embalming**: Vascular injection of embalming fluid after washing of blood and clots removed from arterial system.
2. **Cavity Embalming**: Insertion of fluids and preservatives into abdomen for cavities to substitute evisceration.
3. **Hypodermic Embalming**: Injection of colored solvents under skin to preserve color and retain appearance.
4. **Surface Embalming**: Care to any injuries on the skin and washings to retain life-like appearance via facial expression and related physical attributes.

5.2 Progression of Embalming in the Mid-to-Late-20th Century

While the profession of embalming did not necessarily require long periods of education, it nevertheless required background knowledge in anatomy such that the processes could be completed accurately. Acquisition and preparation of the cadaver included location of the femoral and carotid arteries to insert tubing for fluids as well as proper incisions to insert fluid into the organs [1, 48]. Corpses would often be massaged before and after the insertion of fluids to disperse any blood or clots as well as to combat rigor mortis. By the mid-late 1950s, embalming became increasingly frequent in Europe and educational licenses were required in the United States, allowing professional morticians to take precedence and ensure proper care for the deceased and living. Introduction and continuation of fluids such as ethanol washes, salts, glutaraldehyde, formalin, and dioxin were commonly used by embalming practitioners in the United States, though the amounts and concentrations of the aforementioned solvents as well as the steps for embalming varied greatly [1, 47, 54–56]. By this time, research on embalming fluids was prominent, with figures such as Woodburne & Lawrence using alcohol-glycerine-phenol-formaldehyde embalming formula in 1952 [1]. Furthermore, research in Germany and the US on embalming solutions which did not use formaldehyde or phenol were studied, such as glutaraldehyde, which has been shown to be safer than formaldehyde and equally effective for preservation [1, 47, 54–57]. The increased research on formaldehyde replacements unfortunately did not trump the usage of the solvent; formalin continued to be the standard embalming solvent to present day regardless of its carcinogenic properties.

It was not until the 1960s that the French began to use embalming as a common practice for the deceased [49]. The undertakers, known as "Pompes Fune`bres", actually had no affiliation with the cadavers themselves but instead all of the funeral arrangements prior to burial; nurses, nuns, or midwives would wash and prepare the corpses for burial and services [49]. In Germany, Gunther von Hagens conducted research on polymer vascular injections in 1977 [48]. The injections would replace biological fluids with polymers after the use of formaldehyde, phenol, or other embalming fluids used at the time. This would result in a solidified system which would uphold the same longevity of aforementioned solvents [48, 58]. This process, known as Plastination, requires that the corpse be submerged in a liquid polymer solution under vacuum or injected with liquid polymer before being exposed to some curing gas to solidify [58]. While the preservative effects of Plastination were similar to that of formalin-based methods, its cost and requirement of large volumes limits its use as a standard embalming solvent for common mortuary practice.

Nevertheless, throughout the 20th century, formalin continued to be used as the most common method of embalming. There existed other methods, such as freezing cadavers or injecting large quantities of sodium chloride to entirely replace formaldehyde or be paired with <10% formaldehyde concentration [1]. Unfortunately, with the production of alternative solvents, the acquired sustainability came at a cost of preservative ability; corpses would decompose at a faster rate than that of formaldehyde-based embalming methods. It was not until 1992, with the introduction of Thiel's Method of Embalming, that a minimized-formaldehyde recipe was introduced [1, 48, 55, 59]. Proposed by Walter Thiel, the Thiel embalming method involves very specific preparations of vascular, visceral, and full immersion solutions, though most notably used for its extremely low formaldehyde concentration (0.02%) [59]. By the 1990s, aqueous formaldehyde (formalin) concentrations had varied from as large as 30% to as little as 3% [1, 60–62]. Table 1 shows the required injection and immersion solutions required for the method.

Thiel Embalming Method			
Solution A	***Solution B***	***Injection Solution***	***Immersion Solution***
Boric Acid (3g)	Ethylene Glycol (10 mL)	Solution A (14300 mL)	Ethylene Glycol (10 mL)
Ethylene Glycol (30 mL)	4-chloro-3-methylphenol (1 mL)	Solution B (500 mL)	Formaldehyde (2 mL)
Ammonium Nitrate (20g)		Formaldehyde (300 mL)	Solution B (2 mL)
Potassium Nitrate (5g)		Sodium Sulfate (700g)	Boric Acid (3g)
Hot Water (100 mL)			Ammonium Nitrate (10g)
			Potassium Nitrate (10g)
			Sodium Sulfate (7g)
			Hot Water (100 mL)

Table 1: Walter Thiel embalming method (1992) [62].

While the Thiel model was considered a pinnacle of methodology of embalming in the 1990s, the solutions were expensive to make and difficult to obtain. Additionally, the method itself was argued to be far more elaborate than previously developed processes; the collective desire for a standard embalming method continued to be out of reach for mortuary scientists. The use of phenol, ethanol, and formaldehyde still dominated the embalming market and continues to in present day [1, 60]. Unfortunately, formaldehyde-based and phenol-based preservation methods are soluble in groundwater and transport similarly to arsenic [52]. As a result, research has been conducted on replacements for both formalin and phenol such that the environment and embalmers alike are safer [1].

5.3 21st Century Developments

In the 21st century, embalming methods primarily still use formaldehyde and phenol, though in low concentrations. Much research has been conducted on the comparison between formaldehyde, phenol, and other aldehydes, such as glutaraldehyde, which has been shown to be a much safer alternative [1, 47, 57]. Studies into the environmental and health impacts of formaldehyde over the last century have shown its carcinogenic properties and dangers to the environment [47, 62]. Since the dangers of formalin were known prior to the 20th century, there have been developments of embalming techniques which do not use formaldehyde, or if so, very low concentrations [1, 55, 63, 64]. In the early 2000s, preliminary studies were completed for ionic solvents, such as 1-methyl-3-octyl-oxymethyl-imidazolium-tetrafluoroborate, which are known to be weakly toxic but do not contain formaldehyde and achieve similar preservation results [64]. Additionally, there exist formaldehyde-releasing agents, which can naturally produce formaldehyde via decomposition or generate formaldehyde through a reaction between formaldehyde-containing reagents and byproducts [64]. While these methods limit formaldehyde exposure for practitioners, they continuously produce fresh formalin within the cadaver which can be transported in groundwater and contaminate the environment over time.

The progression toward green embalming methods has created debate on what is considered a 'mortuary practice standard'. The method of embalming and burial has been shown to be debilitating for the environment and the health of active morticians, even with proper ventilation and decreased formaldehyde concentrations [1, 47, 48, 55, 57]. Presently, chemical studies for new solutions used and their economical and environmental impacts have dominated mortuary science study [51, 55, 64, 65].

5.4 Chemical Developments in the Modern Era

Throughout history, the chemical composition of solvents used for cadaver preservation, restoration, and sterilization have dominated the motivation of solvent production. The consistent use of formaldehyde and its related solvents have dominated the modern methods of embalming for the last century. Formaldehyde, also known as methanal (CH_2O), is typically stored in aqueous solution as formalin. Gaseous formaldehyde is typically produced by the oxidation of methanol, via the following chemical reaction:

$$2CH_3OH + O_2 \rightarrow 2CH_2O + 2H_2O$$

Its hydrated form, formalin ($CH_2(OH)_2$), is often injected into the vascular system and is the main component of formaldehyde-based embalming methods [1, 47, 66]. Its counterpart, phenol (C_6H_5OH), is also often used for its ability to sterilize as well as cauterize wounds on cadavers. Both formaldehyde and phenol are able to retain moisture, especially in aqueous form, allowing the cadaver to remain life-like and not appear dry or brittle [1, 66].

5.5 Early 20th Century Embalming Chemistry

In the early 1900s, there existed companies which produced other embalming fluids, such as dioxin. Dioxin debuted as an embalming fluid in as early as 1909, produced H.S. Eckels and Company, though it is accredited to being sold commercially from 1920-1940, and contained a mixture of formalin and hydrogen peroxide, and was claimed to "... have twice the power of disinfection, drying, penetration and preserving of other fluids which contain the poorer grades known as Commercial Formaldehyde," [56]. Formaldehyde-free substances, such as glutaraldehyde, have continued to be used to present day and are considered prominent competitors to formaldehyde.

Glutaraldehyde first debuted as a method of sterilization in hospitals and industrial establishments and replaced formaldehyde in the leather tanning industry in the 1950s [57]. It has not been shown that glutaraldehyde contains any carcinogenic properties, though it can cause skin irritation for prolonged exposure [57]. Its counterpart, formaldehyde, has been shown to be carcinogenic, debilitating for the respiratory system, and extremely irritating on skin, causing contact dermatitis [47, 50, 57]. Glutaraldehyde has been shown to have a low threshold for inhalation, with mild irritant effects appearing at 0.3 PPM and significant effects at > 1 PPM [47, 57]. On the contrary, formaldehyde can cause severely irritating respiratory effects as low as 0.5 PPM, and it is said, "If you can smell formaldehyde, you are overexposed. There is no safety margin," [57]. The danger of formaldehyde for embalming practitioners motivates the cessation of its use in modern embalming methods.

5.6 Late-20th Century to 21st Century Chemical Progression

Other potential replacements for formaldehyde include ethanol-glycerin, introduced in 2012, which can be added at different ratios for BMI values of cadavers [1, 59]. Injections are completed after the cadavers are washed and prepared, and then lastly submerged in 65% ethanol solution by volume [59]. After bodies are stored at 3 to 5°C for a specified period, they are shown to retain their appearance for approximately 3 years [59]. Embalming with ethanol has been used throughout history for washes and injections for cadavers [1]. Furthermore, glycerine has commonly been used with formaldehyde or phenol for modern methods, but a mixture of both ethanol and glycerine with thymol powder has shown long-term preservation with less respiratory risk [1, 59, 66]. Unfortunately, using ethanol can have high explosive risk due to its flammability, and embalming laboratories must be well ventilated to prevent hazards as well as respiratory risks for the use of large quantities of ethanol.

Formaldehyde-releasers are often considered as viable replacements for formalin solutions used in mortuary practice. Common examples include decomposition releasers, such as bronopol and methenamine. The following reactions show the decomposition or aided decomposition reactions for both bronopol and methenamine, respectively:

$$C_3H_6BrNO_4 \rightarrow CH_2BrNO_2 + 2CH_2O \tag{4}$$

$$C_6H_{12}N_4 \xrightarrow[2H_2SO_4]{6H_2O} 2(NH_4)_2SO_4 + 6CH_2O \tag{5}$$

It has been shown that bronopol has a higher percentage of formaldehyde recovery yield after one year in water, at 3.5%. In comparison, there was no apparent formaldehyde released by the methenamine, which was attributed to the slightly basic pH (0.1 M concentration at pH 7.4) [64]. Higher concentrations and lower (more acidic) pH levels have attributed to greater formaldehyde production with methenamine. For bronopol, higher concentrations also attributed to greater formaldehyde production, with a concentration of 0.273 M producing up to 19% formaldehyde recovery yield [64]. The higher recovery of formaldehyde correlates to its increased production with time, ensuring a cadaver which is preserved for longer periods due to the reaction producing and continuous release of fresh formaldehyde.

5.7 Dangers of Traditional Solvents and Burial

While there exists a plethora of different solvents for embalming practices, not all methods are entirely progressive. Naturally, formaldehyde has been shown to be extremely carcinogenic and dangerous for the environment [1, 47, 57, 63, 64, 66]. Unfortunately, its persistence as a state-of-the-art embalming solvent has overshadowed studies for newer solvents to be developed. A significant competitor, glutaraldehyde, has been studied and shown to be similar in effectiveness and non-carcinogenic [47, 57]. Unfortunately, as with all embalming fluids, their ability to produce strong fumes and irritant characteristics requires a significant amount of knowledge and precaution to be considered for their continued use [1, 47]. Nevertheless, the commercialization of embalming products by companies and mortuary scientists has allowed future embalming to be explored with different solvents and methods that may become better for the planet and future practitioners [1, 55, 57, 59, 64, 65].

Unfortunately, formaldehyde-releasing agents are often used in cosmetic products and have been shown to cause contact dermatitis on the living. For example, in certain cultures or groups, individuals may kiss their deceased relative. In this case, formaldehyde releasing agents may cause contact dermatitis to the living; however, this is more commonly caused by the use of formaldehyde-releasing agents in cosmetic products such as makeup or shampoos [64, 67]. While other solvents are also shown to be mildly irritating, such as phenol, glutaraldehyde, and dioxin; the use of formaldehyde has shown to be the most dangerous for this process yet is continuously used as a commonplace for modern embalming.

While the practice of embalming itself is full of debate, the burial practices and impact on the environment have been shown to be dangerous in its own right. For example, the carrying of formaldehyde in groundwater can be dangerous for both humans and animals alike and has motivated laws to be put forth to ensure the safety of the human population and environment alike [50, 52, 68, 69]. The practice of burial limits long-term funeral practices due to overcrowding of body disposal. While cremation may be a suitable answer to this issue, the emissions of gases from the process are just as damaging to the environment as the runoff of formalin in groundwater [52, 69].

5.8 Embalming and Burial Significance in Criminology

The practice of embalming has in turn permitted the ability of exhumation of cadavers to be completed for various purposes. For example, the death of an unknown child in Philadelphia in 1957 baffled the nation as for over 30 years he was never identified. It was not until 1998 that police were given authorization to exhume his remains for DNA, and by this he was able to be identified as Joseph Augustus Zarelli [70]. The case of the 'Boy in the Box' is one of many in which bodies were exhumed for criminal investigations for their identity or autopsy. The process of embalming has allowed the bodies to retain their appearance upon death such that investigation may be conducted post-mortem, in some cases, giving families closure as to their cause of death or identity.

5.9 Overview of the Mortuary Science in the Modern Period

Overall, the historical progression, chemical composition, and cultural impacts of embalming throughout history have shown its significance as a science. The practice of embalming has continuously progressed the cultural relationship between grief and closure and is often interconnected with religious practices. Furthermore, embalming has motivated the study of anatomy and con- tributed significantly to medical practice as it has allowed scientists to discover the inner-workings of the human body. Presently, the ritual of embalming pre-burial is considered a standard for post-mortem handling, with over 50% of American deceased embalmed each year [71]. As research continues methods that are safer for the environment and for embalming practitioners, the progression of mortuary science continues to shape life after death for years to come.

6 Conclusion

From the Prehistoric to Modern Era, mortuary science has been deeply interconnected with cultural practices. The methods of mummification, dissection, and preservation for cadavers have individually impacted the future of embalming research. For the prehistoric civilizations, the complex chemical properties developed were far from intuitive yet vital for societal progression and connected to religious practices. In the Middle Ages, the curiosity for the functionality of the human body resulted in new methods for preservation and care for cadavers which could be applied for burial. By the Modern Era, mortuary science developed as a practice strictly for burial and cultural standards. Presently, the ever need for sustainable and safe embalming standards is necessary and vital for the future of mortuary science. Nevertheless, the relationship between life and death; embalming and chemistry; show the future of mortuary science and embalming practice, something that will impact death for the rest of human life.

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