



The Restoration of Mummies in Ancient Egypt: A Review

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Abstract

The human deterioration factor plays a major role in the mummies' deterioration, and it is no less important than other deterioration factors, whether in the burial environment or the exposure environment in museums or stores. Looting is considered one of the most serious human deterioration factors, which led to the destruction of some mummies during the different periods in ancient Egypt. This study aims to explain the impact of human deterioration on mummies, describe its aspects of deterioration, and present the ancient Egyptian restoration and conservation techniques and materials used through different periods. The ancient Egyptians used different methods in restoring mummies, especially in the reassembling process of separated or broken parts. Examples of reassembling methods used were wooden splints such as palm wood splints, palm bark, reed sticks, fibres from palm trees, and wooden pegs. The resin technique and linen with resins were also used. The materials used in the restoration process were resins and oils such as mastic, myrrh, and beeswax. Different plant fibers such as wood, linen, palm fibres, reed, etc. The metal "iron" was also used in this process. This study showed that the ancient Egyptians are considered the pioneers of restoration in the world, and they preceded others in this field. It was also found that most of the materials used in the restoration are resistant to microorganisms and insects, and improve the mechanical properties of mummies.

Keywords: Mummies, fractures and separations, restoration, reassembling, splints, compensatory parts, resins, plant fibres.

1. Introduction

Mummification is considered one of the prominent and illuminating signs in the history of the ancient Egyptian civilization. Mummification passed through various developments during ancient Egyptian times [1-5]. It reached the peak of its progress in the era of the New Kingdom. Then mummification began to weaken, starting from the Third Intermediate Period until the Greco-Roman era. But during the eras of weak mummification, some wonderful cases of mummification were found, which amounted to the method of mummification in the era of the New Kingdom, but that was not general. Many scientists and researchers talked about mummification methods in different eras [6-18], and therefore this will not be discussed in this study.

Many references discussed the deterioration factors of mummies and organic materials resulting from the influence of the burial environment, or as a result of the influence of unsuitable environmental conditions (physical - chemical - biological) [19-41]. Few references discussed the impact of human deterioration on ancient mummies. The looting of tombs is considered one of the biggest factors of

human mummies deterioration, as this led to the loss of many archaeological materials, especially mummies and this was maybe due to that what is always believed about the treasures inside mummies.

Grave looting has occurred over a long period up to the present time. It can be said that mummies of high value, especially royal mummies, were subjected to looting and vandalism [42-46]. Accordingly, there was a separation and loss of large parts of the mummies [44]. The looting of the royal mummies led to a need for the priests of the Twenty-first Dynasty to transfer them to the first cache of mummies in Deir el-Bahari in Luxor, which was discovered in 1881, and the second cache of mummies in the tomb of King Amenhotep II in Deir el-Bahari in Luxor, which was discovered in 1889 AD. The priests during that period conserved and packaged the mummies before transferring them to the two caches mentioned above [43].

There are many examples of the separation of mummies as a result of the looting of graves, including the mummy of Queen Ti, formerly known as the old lady, which was separated into multiple parts, especially in the area of the feet, with the loss of the

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right hand and a large part of the chest up to the pubic area (Fig. 1a) [42]. Another example of vandalism resulting from the theft and looting of tombs was the transformation of the mummy of King Ramesses VI into broken parts. On examination, this mummy was found separated into 187 pieces, and a piece of broken ribs was also found lying in front of the ankles [43]. This mummy was stored in Room No. 55 on the second floor of the Egyptian Museum in Tahrir, then it was moved to the basement store in the same museum (Fig. 1b), and it is now preserved in the National Museum of Egyptian Civilization after it was recently collected and restored by Egyptian conservators. Another example of deliberate vandalism was the remains of a pair of mummified legs of Queen Nefertari, wife of King Ramesses II (the nineteenth dynasty, around 1250 BC) found in her tomb in the Valley of the Kings, and these remains are now displayed in the Egyptian Museum in Turin (Fig. 1c) [44-45].

The vandalism was not limited to the mummies of kings only but also extended to the mummies of the middle class, such as the mummy of the daughter of the high priest, which was found in the burial chamber of tomb No. TT-95, one of the tombs of the nobles, dates back to the Eighteenth Dynasty (about 1550-1300 BC) [46]. The influence of tomb thieves also extended to direct destruction by cutting up mummies and placing them in water over a high fire to seize the resin that was used in lighting [45].

The priests worked to restore what was left of the deliberate destruction in different eras [47]. The splints discovered by Petri and dating back to the Old Kingdom (the Fifth Dynasty) are among the oldest examples of reassembling fractures in various parts of mummies, especially at the level of the hands and feet [48]. There are multiple examples of reassembling and reassembling royal mummies, especially in the twenty-first dynasty [49]. The priests worked on the development of the process of restoring and conserving mummies through the ages by using splints of various shapes made of wood and linen, or linen saturated with resin [43], as well as using palm bark and solid reed sticks for the process of reassembling fractures [48]. In cases of missing parts of the body, prostheses made of flax, sticks, or reeds with resins were used [50], and sometimes animal or human bones were used to replace lost or shattered limbs [51].

Owing to their great value as masterpieces to humanity, the conservation of cultural heritage materials, on top of which are human remains, is considered an advanced multidisciplinary and interdisciplinary research area that involves significant contributions of different techniques [52,53].

This study aims to explain the impact of human deterioration factors on the destruction of Egyptian mummies through the ages. It also aims to survey examples of destructed mummies and explains the method of ancient Egyptian restoration and conservation and the materials used in these processes.

2. Reassembling Methods of separated or broken parts of mummies

As a result of the human deterioration resulting from the looting of the tombs, many parts of the mummies were exposed to falling off, fractures, and destruction. The ancient Egyptian (often the priests of the temples) used many methods to return these parts to their correct places in the human or animal body. Among the methods commonly used are the following:

2.1. Reassembling methods with wooden supports

The ancient Egyptians' "priests or those responsible for the conservation of destructed mummies" used wood derived from different types and then tied them with linen bandages saturated with resin in reassembling the separate parts, especially the legs, hands, and head. The oldest examples of this technique in different eras were as follows:

2.1.1. The Old Kingdom

The following examples date back to the Old Kingdom:

- The splints discovered by Petri, which were dated back to the Fifth and Sixth Dynasties [48] were made of three wooden supports made of palm bark, then wrapped with linen [54]. In some splints, fibers from palm trees were also found (Fig. 2a) [48].
- The splints discovered in Luxor, Deir el-Medina, included several human mummies with multiple fractures. The femoral fracture was treated by placing palm wood or palm bark around the fractures and then tying it with linen (Fig. 2b) [47].
- There is another case of a fracture in the middle of the right femur of a girl who died at about 14. The broken femur was fixed with four splints made of palm wood wrapped with linen and resin (Fig. 2c). The length of the reassembling increased just above the fracture to a point below the knee.
- Sometimes they used two splints of wood on top of each other. Each splint was circular to wrap around the fracture, and then the wooden supports were fixed with a thin strip of linen saturated with resin. Then the second splint was placed on top of the first in the same manner (Fig. 2d).
- They also used splints made of palm wood surrounded by linen wraps to treat fractures of the

forearm and ulnar bones. It was also noticed the presence of plant fibers "palm fibers" attached to the ulna and stained with blood, and this may be due to

the occurrence of death as a result of bleeding, and these plants may have been used to stop or reduce bleeding (Fig. 2e) [43].



Fig. 1. Some aspects of deterioration of some mummies as a result of looting by thieves: (a) Queen Tiye mummy [54]; (b) Mummy of King Ramses VI [55]; (c) Remains of the mummy of Queen Nefertari [45].

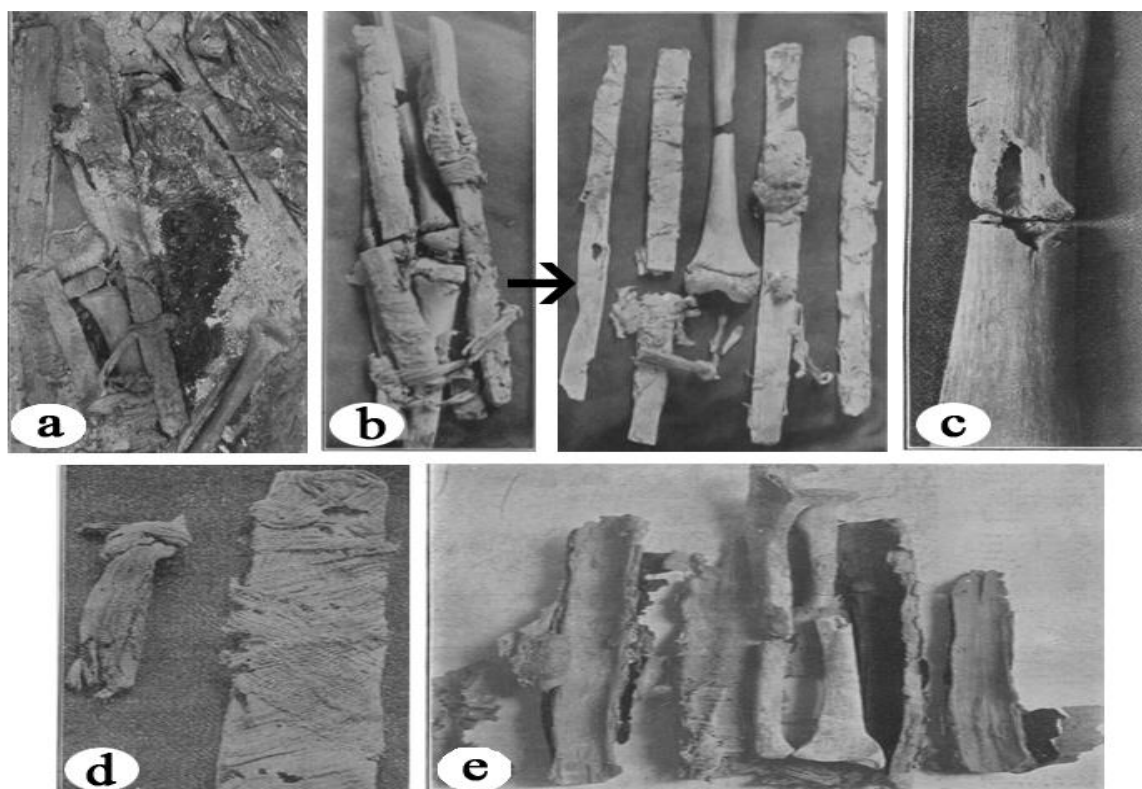


Fig. 2. Some types of splints used in the Old Kingdom: (a) The shape of splints at the moment of their discovery in excavation [43]; (b) Some wooden splints from the Sixth Dynasty - Old Kingdom [54]; (c) Fractured femur after removing the wooden supports [43]; (d) Reassembling method with splints on top of each other to support the femur [43]; (e) Reassembling and supporting of a fractured left forearm of an unknown mummy using various materials [43].



Fig. 3. The restoration processes of the priests of the Eleventh Dynasty for some mummies of the New Kingdom: (a) The restoration of a fracture in the right forearm of the mummy of King Siptah [55]; (b) Restoration process of the thigh fractures of the mummy of King Amenhotep III [55]; (c) The restoration process of the foot of King Amenhotep I [56].

3.1.3. Twenty-fifth dynasty

The mummy of an adult man called Osirmose, whose job was to guard the Temple of Ra during the Twenty-fifth Dynasty "747-656 BC" [57], was restored. The mummy is in the Royal Museum of Art and History, Department of Egyptian Collections in Brussels, Belgium since 1874, and bears No. E.5889 [58] and by examining a three-dimensional CT scan, the method of restoration applied to this mummy was by using a wooden board placed on the front side of the body and another wooden board on the back side

of the body, and a wooden stick was inserted in the rib cage until reaching the edge of the bottom of the skull extending to the pelvis, to support the multiple fractures in the rib cage and damage to the spine and the head (Fig.4a). Layers of linen wraps impregnated in resin were also wrapped around the head and the upper region to include the chest. He also used a metal wire and wrapped it around the head and the upper part of the mummy, as in (Fig.4b), to increase the fixation of the supports to preserve the shape of the destroyed body [59].

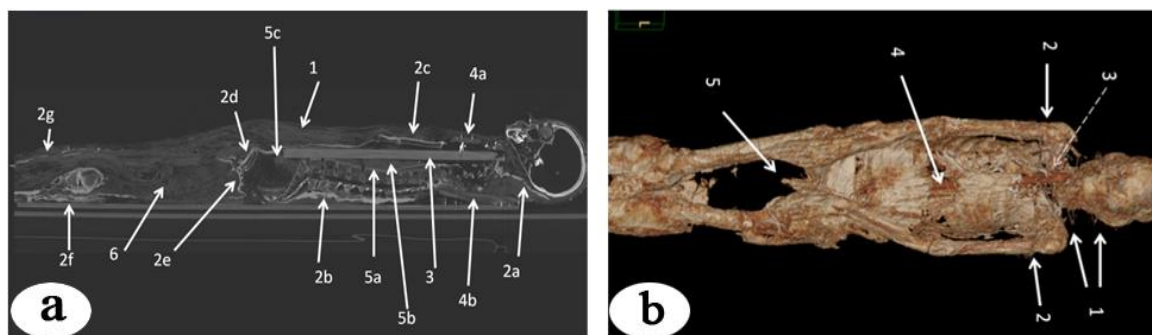


Fig. 4. The restoration process of Osirmose's mummy: (a) Restorations inside the mummy's body shown using a CT scan [59]; Restoration process for the external parts of the mummy [59].

2.1.4. Restoration of Sacred animals

The mummification of votive animals was performed by the ancient Egyptians in the Late Period using various methods [60]. There is a case of an Egyptian crocodile mummy displayed in the Musée des Confluences in Lyon - France [61] dating back to the Late Period (about 722-332 BC). [62], MHNL

90001850 [63]. In the study, it was discovered that there were no viscera or spine with the decomposition of the inner part, and this may be because the crocodile had decomposed before the mummification began, and during its mummification, the viscera and bones were removed and a wedge of wood immersed in resin was placed to support the mummy from the inside (Fig. 5) [64].

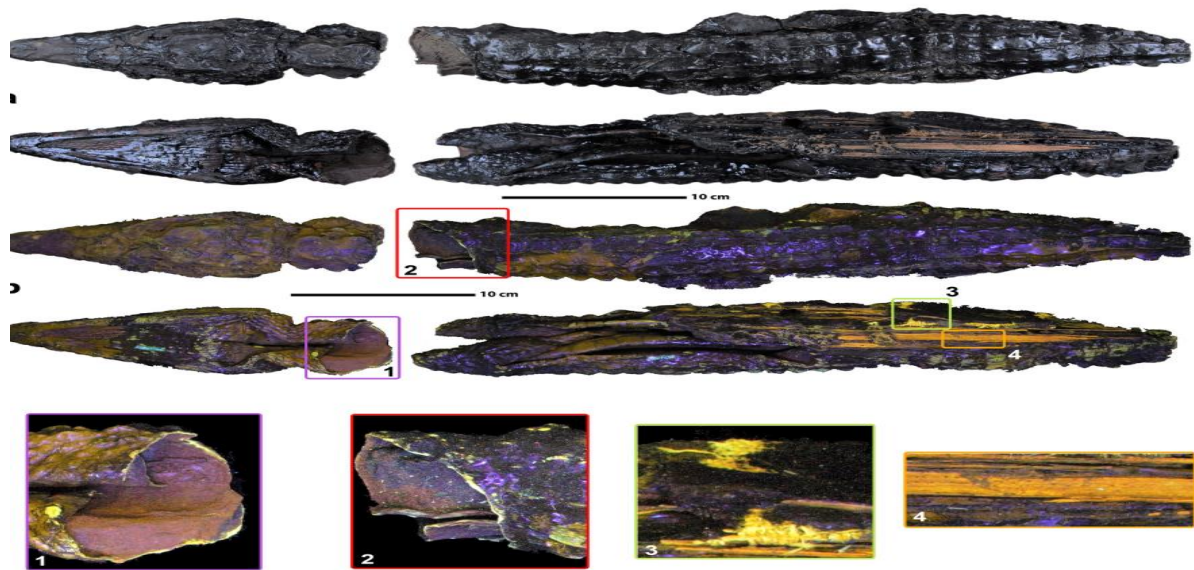


Fig. 5. Restoration Process of a crocodile from the Late Period [64].

2.1.5. Ptolemaic Period

Wooden supports were used to repair mummification damage or to conserve mummies after they were stolen. The best example of this is the mummy known as the Neapolitan mummy, which is of a man aged 35-40 years and bears no. 2343 preserved in the Archaeological Museum in Naples. The mummy was studied within the framework of the Anubis Project,

where X-rays revealed the use of wooden supports in the thigh area fixed with linen immersed in resin (Fig. 6a). The study also revealed the absence of the feet. They were replaced with wood by placing a rectangular piece of wood transversely at the bottom of the coffin and a piece of sharply pointed wood adjacent to the foot, and the two parts of the wood were joined together using metal screws (Fig. 6b) [54].

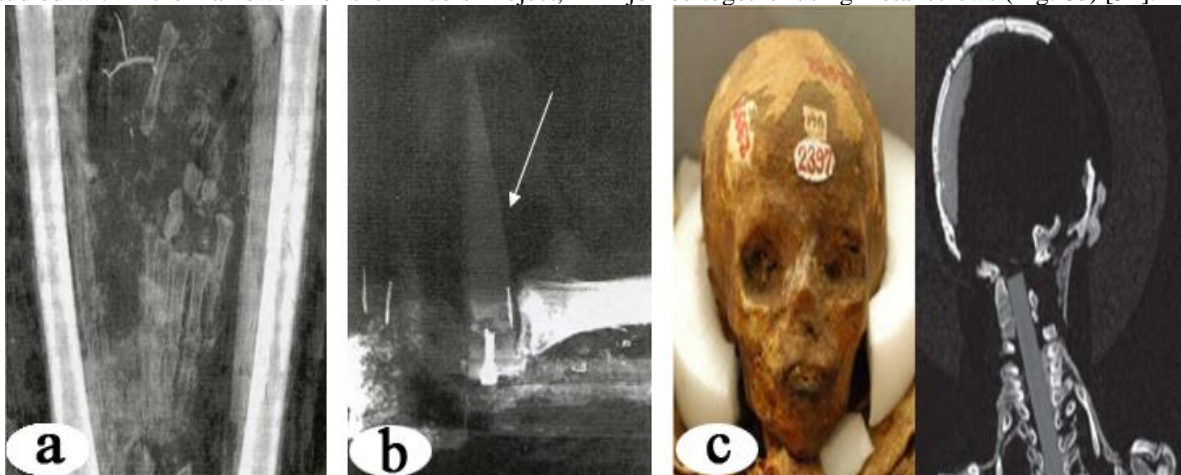


Fig. 6. Restoration processes for some mummies from the Ptolemaic and Roman periods: (a and b) Restoration processes for a mummy dating back to the Ptolemaic period [54]; (c) Restoration process during the mummification process of a mummy of a child from the Greco-Roman period [54].

2.1.6. Roman period

Due to the decline of mummification and the prevalence of errors during mummification, fractures and separation of parts of the body occurred [65]. An example of this is the mummy of a child found in Thebes dating back to the Greco-Roman era [66] and

is currently on display at the National Museum of Natural History in Philadelphia. And it bears the number P381235 [67]. In the study conducted by Hunt with a three-dimensional CT scan, it was discovered that there was wooden support inside the body to connect the head as a result of a neck fracture, and

during mummification, they made a support for the neck area using a wooden wedge and resin (Fig. 6c) [68].

2.2. Reassembling using resins or linen with resins

Embalmer or those who are responsible for the restoration and conservation of damaged mummies in the past had used special resins to collect the delicate parts such as the fingers of the feet and hands or the head and neck with a substance consisting of resin such as mastic with wax [69]. Linen saturated with resin was also used to adhere to the separate parts [56] such as the separated head or hands and feet [70].

One of the most famous examples is the treatment of the mummy of King Tutankhamun, who ruled Egypt in the New Kingdom - the eighteenth dynasty "1334 to 1325 BC". A three-dimensional CT scan showed the presence of a fracture in the thigh bones, and it was identified that there were traces of resin materials have been used to treat the fracture, some of which were attached to the surfaces of the bones. The resins have also been used to collect part of the toe (Fig. 7a) [48].

It can be assumed that embalmers preferred to use cloths impregnated in resins instead of wood because it was easier to collect the parts or build the limbs and obtain the desired shape with linen. This explanation seems to be confirmed by the fact that wood was also scarcer, and expensive, and more effort was taken to form large or simple anatomical parts, such as the leg and feet, and by contrast the ease of reassembling the various parts or making missing parts such as the single feet and hands of linen impregnated in resin [54].

Another example is the mummy of King Amenhotep I, who ruled Egypt in the eighteenth dynasty "1525-1504 BC" [71]. The results of the 3D CT scan showed that the mummy had undergone restoration and conservation processes [56] as a result of multiple injuries after mummification and burial in the cemetery designated for it [72]. Tomb thieves are likely the cause of the destruction [73]. The priests of the Twenty-first Dynasty restored and preserved the mummy, which was transferred to the royal cache of Deir el-Bahari, which was discovered in 1881 [74]. The mummy was completely wrapped and was one of the few royal mummies not dismantled in the modern era [75]. The results of the study conducted by Saleem and Hawass showed that the restoration and conservation processes that took place on this mummy included the following:

1. Fixing the head and neck (broken neck vertebrae), separated from the body, with a strip of resin-treated linen to keep the head and neck in line with the body (Fig. 7b).

2. Covering a defect in the anterior abdominal wall with a strip of resin-impregnated linen and placing an amulet underneath (Fig. 7c).
3. Place the separated upper left limb next to the body and wrap it around the body with linen saturated with resin.
4. Wrapping the right forearm individually with linen impregnated in resin (Fig. 7d) [56]. In the Ptolemaic era, mutilated bodies appeared as a result of embalming operations. Wood-Jones indicates four cases of missing mummies, including parts or organs. The embalmers treated the body by replacing the missing parts with linen saturated with resin, which is as follows:
 - **The first case** of a mummy of a woman, in which both hands were replaced with linen saturated in resin by shaping, and it is clear that the mummy's skeleton was damaged, especially the limbs [70].
 - **The second case** of a woman's mummy showed that the heel bone, metatarsal, and left patella were formed with linen saturated in resin, and the fingers were simulated with pieces of reeds to represent the toes.
 - **The third case** is the mummy of an elderly man. The body was in good condition, but the right hand was missing and was replaced by linen impregnated with resin.
 - **The fourth case** is a mummy of a woman. The bones of the hands were not found, and both hands and arms were formed with linen impregnated with resin. The construction method was used on fragments of the left forearm to complete the missing part with linen impregnated with resin (Fig. 7e).

Recently, a case from the Ptolemaic period similar to the above was discovered, and utilizing X-rays in the Rijksmuseum (a museum specialized in displaying the history of science and medicine, located in the city of Leiden - Amsterdam - the Netherlands); it is a mummy of a young child of unknown gender. The X-rays showed that the following bones are missing:

- ❖ The entire spine and most of the ribs are in the thoracic cage.
- ❖ Most parts of the pelvis, hands, and wrists.
- ❖ Shoulder, collarbone, and parts of the long bones.

The embalmers made a formation of the hands and long bones with linen saturated with resin.

There is also the mummy of an unknown person from the Ptolemaic era that was displayed in the Calouste Gulbenkian Museum in Portugal. It was identified by using X-rays that the mummy was equipped with an arm formed from linen saturated with resin without the use of wood (Fig. 7f) [50].

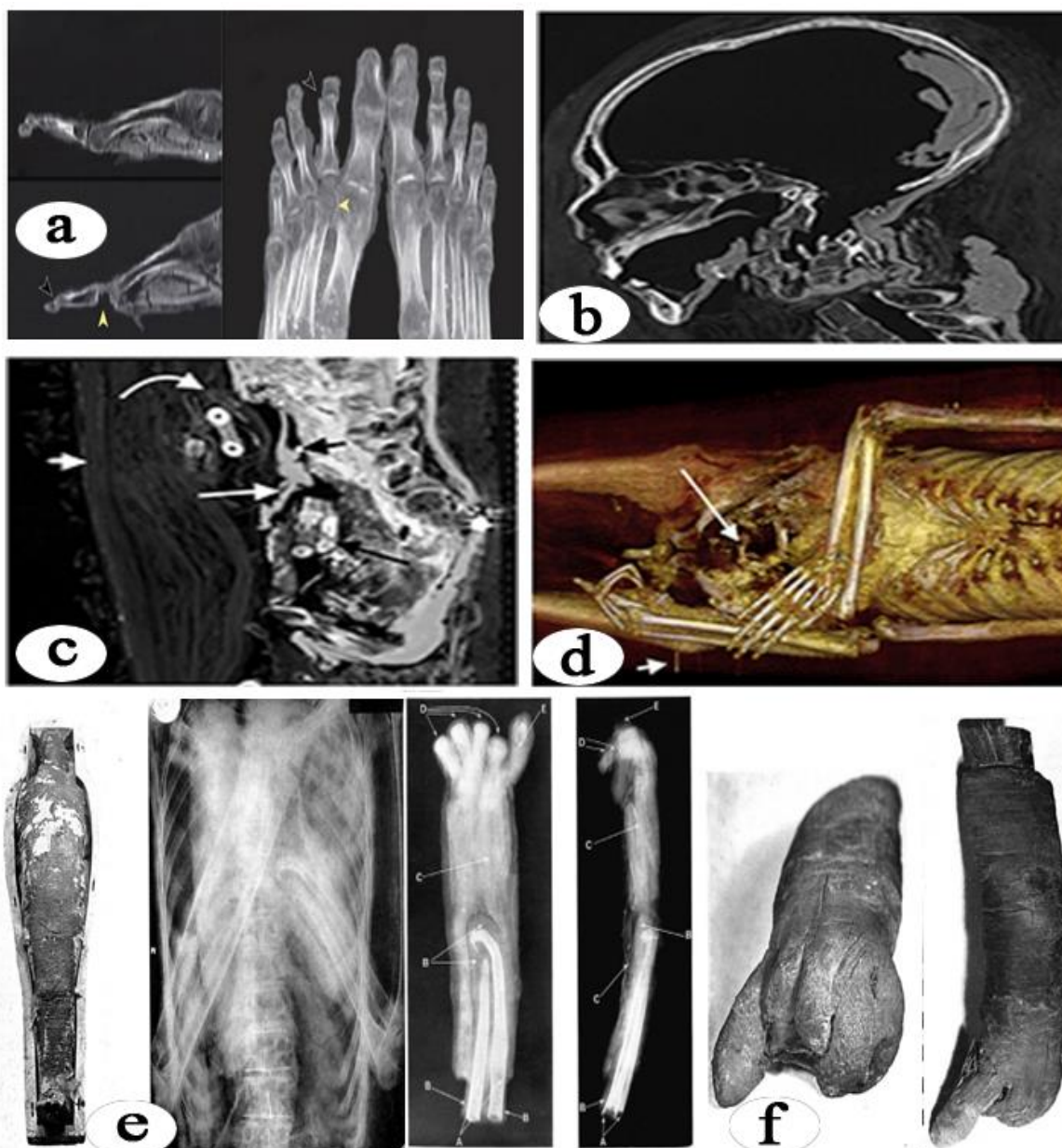


Fig. 7. Restoration processes using linen and resins: (a) The use of resin in the restoration of the mummy of King Tutankhamun [48]; (b, c, and d) Reassembling some parts (head, abdomen, and left hand) of the mummy of King Amenhotep I [56]; (e) Restoration (completion) of the left forearm of the mummy of a lady from the Ptolemaic period [50]; (f) Reconstruction of the arm of an unknown mummy from the Ptolemaic period [50].

2.3. Reassembling methods using metals

The attempt to treat bone fractures, especially long ones, is one of the most difficult cases, which often requires surgical amputation, and as a result, death occurs. The missing parts or fractures are treated in the mummification process with splints or with prosthetic replacement parts. Mostly these interventions are by using wood, linen or resin, or linen impregnated with resin, or overlapping materials together, etc.

However, it was recently discovered that an internal fixation of the knee was used using the metal "iron metal", such as the mummy in the sarcophagus of Osermonto, who was a minister to King Tutankhamun during the Eighteenth Dynasty and was the son of Bisenmut, priest of the god Montu, Lord of Thebes. Carbon 14 analysis confirmed that the owner of the mummy died around 600 BC, and not during the date of the sarcophagus, which dates back to the

Osermonto era (1300 BC). Accordingly, it was found that the mummy was replaced in subsequent ages, and the name of the owner of the two bodies present in the Osermonto sarcophagus and this mummy was not inferred. It is preserved at the Rosicrucian Museum in San Jose, California, since 1971. In 1996 AD, a medical team led by the famous Egyptologist, Dr. Wilfred, examined the mummy, and radiological images showed that an iron nail was installed inside the right knee marrow. This nail is designed in a way that gradually decreases at its tip, which extends to the thigh bone, and it has three edges that work to stabilize the iron nail inside the knee and prevent it from rotating. It is clear that there is a resinous substance that helps stabilize the joint, and it has been defined as cedar gum, and some other organic resin mixtures (Fig. 8) [48].



Fig. 8. Reassembly of a knee of a mummy of a woman using iron metal [50].

3. Materials used in the restoration process of mummies in Ancient Egypt

3.1. Resins and oils

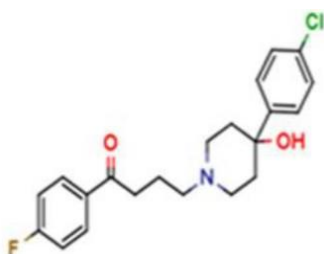
Natural resins and oils were used in the mummification process in ancient Egypt. It can be said that the majority of references often mentioned the name of the resin, or oil but did not mention its type, and this is due to the fact that the definition of these materials is considered one of the complex processes that need advanced and high-quality instruments, in addition to the scientific experience that will explain

the results. The following is a list of some of these materials, for example, but not limited to:

3.1.1. Mastic resin

Mastic resin has many characteristics that encouraged embalmers in ancient Egypt during different ages to use it, whether in painting the body after the completion of the embalming process (to isolate the body, which is one of the scientific principles on which the embalming process was based), or in the restoration processes through ages in ancient Egypt. These features included antifungal, antibacterial, insect-repellent, and even anthelmintic activity [76-

78]. Abdel-Maksoud and El-Amin [3] said that The Egyptians had used mastic resin in the mummification process. It probably had religious significance even when used for mummification. Some authors confirmed the use of mastic resin in the mummification process [11,79,80].



Chemical structure of gum mastic resin (Al-Haddad et

3.1.2. Juniper

Juniper was used in the First Intermediate Period. Juniper cones (generally *Juniperus phoenicea* L.) have often been found in ancient Egyptian graves [3]. Phytochemical studies reveal that *Juniperus phoenicea* contains a large variety of compounds, mainly diterpenoids, bioflavonoids, lignans, phenylpropane glucosides, two furanone glucosides, bis-furanone propane derivatives and norterpene and sesquiterpene glucosides [82].

3.1.3. Myrrh

Myrrh can be defined as an oleo-gum resin produced by different *Commiphora* species. It is constituted by 3–4% impurities, 7–17% volatile oils, 25–40% alcohol soluble resins, and 57–61% water soluble gum. The volatile oil fraction was reported to be composed of various bioactive constituents including eugenol, lemon, esters, cinnamaldehyde, cuminaldehyde, cadinene cumic alcohol, m-cresol, limonine, dipentene, pinene, sesquiterpenes, Furanos-sesquiterpenes heerabolene, and terpenes, alcohols, α -camphorarene, myrcene, Z-guggulsterone, aldehydes I, II, III guggulsterone [83].

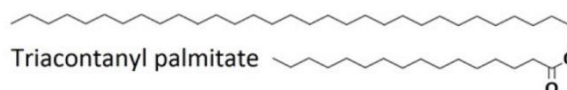
Myrrh, antiyw in ancient Egyptian, was fragrant gum, the essential resin in the shape of small yellow-red lumps. Myrrh was imported from Somalia and southern Arabia, commonly used during the New Kingdom to stuff and massage on and into mummies [3].

3.1.4. Beeswax

Beeswax played an essential role during Antiquity in technology, symbolism, and art. Using beeswax limited rehydration of the embalmed body [84].

Beeswax was used for different purposes in ancient Egypt. For example, it was employed in the

mummification process and was often used to model. It was also used as an adhesive during the Middle Kingdom, and the New Kingdom in ancient Egypt as was confirmed by Lucas [3]. Beeswax has antimicrobial effectiveness against bacteria and fungi. It also has rich hydrophobic protective properties [85]. Beeswax is a material that consists of a mixture of several compounds mainly palmitoleate, palmitate, and oleate esters of long-chain (30–32 carbons) aliphatic alcohols. Concerning its chemistry, an approximate chemical formula for beeswax is reported to be $C_{15}H_{31}COOC_{30}H_{61}$ [86].



Molecular structure of triacontanyl palmitate as the major component of beeswax (Abdikheibari et al., 2015)

process< It contains essential oil and some essential ingredients (α -pinene, myrcene, limonene, terpinolene, and α -terpinene), which have a major effect on bacteria, fungi, and some insects. This may explain the reason why the mummies were protected [3]. It is also used to help stabilize the joint of the fractured bone of mummies [48].

3.2. Plant fibres

Plant fibers were also used in the restoration process of mummies in ancient Egypt. The following is a list of some of these materials, for example, but not limited to:

3.2.1. Wood

Wood fiber is mainly composed of cellulose, hemicelluloses, lignin, and extractives. The proportions of these components differ in hard and soft woods. The percentage of cellulose is between 40-44% in hardwood and softwood. The hemicellulose percentage is 15-35 in hardwood, and 30-32 in softwood. The rate of lignin is 18-25 in hardwood, and 25-32 in softwood. The extractives percentage is 2% hardwood and 5% softwood [87]. Chemical composition varies with tree part (root, stem, or branch), type of wood (i.e., normal, tension, or compression) geographic location, climate, and soil conditions [88].

3.2.2. Linen

Linen fibers are considered one of the earliest materials that have been used by the Egyptians because they are long and strong. Linen consists of cellulose, which is the principal element, and non-cellulose compounds such as hemicellulose, Pectin, lignin, fats and waxes, mineral salts, natural coloring matter, and watery soluble compounds Abdel-

Maksoud et al [89]. Linen has been used in the mummification process as bandages or wraps through different ages in ancient Egypt. It was also used in the restoration process of mummies as mentioned above.

3.2.3. Palm fibers

The palm leaf sheath fiber is considered an abundant agricultural byproduct due to the necessary regular pruning process of the palm tree by removing loose mats to keep the tree attractive and safe. The analysis showed that the palm fibers were composed mainly of cellulose, hemicellulose, and lignin [90]. Ancient Egyptian people have used palm fibers in their life. Palm fibers were identified with other 15 plant species commonly used as fibrous plants by the ancient Egyptians [91]. One of the multiple uses of Palm fibers is its use as a restoration material for mummies in ancient Egypt.

3.2.4. Reed

Reed fibers were also used in the restoration process of mummies in ancient Egypt. Solid reed sticks were used for the process of Reassembling fractures [48].

3.3. Metals

An iron nail was installed inside the right to stabilize and prevent it from rotating. Resin material or a mixture of resins were used to stabilize the joint [48].

4. Conclusion

Human deterioration represented by looting and theft leads to major problems for mummies such as fractures, separations, and sometimes the destruction of large parts of the mummy. The ancient Egyptian is considered the first restorer in history and preceded others in this field. He excelled in the restoration of mummies during the different Egyptian eras using different materials and techniques that served the required purpose. The most common techniques used in the conservation of mummies by ancient Egyptians were assembling methods with wooden splints, or splints made from other fibers such as palm fibers, and reeds. They also used wooden splints attached to the linen bandages in the form of tapes saturated with resin. Another technique used was resins or linen with resins. An assembling method using (iron) was also used. Some materials have been used with the techniques that were mentioned above. Some of these materials were resins and oil such as mastic resin, Juniper, myrrh, beeswax, and cedar oil. Plant fibres such as wood, linen, palm fibres, and reeds were used. Metal (iron) was also used.

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