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THE INVESTIGATION AND CONSERVATION OF A GAZELLE MUMMY FROM THE LATE PERIOD IN ANCIENT EGYPT

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ABSTRACT

A Late Period gazelle mummy housed in the Agricultural Museum in Cairo, Egypt was selected for this study. The mummy showed different signs of deterioration, such as white spots, missing tissue, gaps in the linen bandages, and accumulated dust. This study aims to describe the signs of deterioration; to explain the mechanisms of deterioration, and to apply appropriate conservation techniques to the mummy. To achieve these goals, the mummy was first examined by means of visual assessment, AutoCAD, light microscope, microbiological investigation, scanning electron microscope (SEM), Fourier transform infrared spectroscopy (FTIR), amino acid analysis and x-ray diffraction (XRD). The conservation techniques used were mechanical and chemical cleaning, consolidation of wrappings and bandages, completion processes and reconnecting loss part of the gazelle's leg. The results of investigation revealed that the mummy suffered from a loss of amides in the bone which increased their crystallinity, as well as oxidation and hydrolysis mechanisms. The wrappings were identified as *Cyperus papyrus* L. The mechanical and chemical cleaning used removed the surface dust and dirt without damage to the components of the mummy. The wrappings and bandages became strong after using Klucel G as a consolidant material. The paste used in the completion process gave significant results in filling cracks and missing parts of the mummy's back. In general, all the conservation processes of the mummy revealed its aesthetic value.

KEYWORDS: Mummy, deterioration, amino acids, FTIR; XRD, conservation.

1. INTRODUCTION

The Egyptians depicted their gods not only as humans but also in animal form. This does not mean that these gods in animal shape were mere animals. Just as the Egyptians did not worship images or human beings, they did not worship animals, but gods.

In prehistoric times, animals were sometimes ritually buried: predynastic graves have been found with gazelles wrapped in mats and provided with funerary gifts such as pots of food and drink. This indicates that people were concerned that these creatures be sustained in the afterlife. Scattered data from the Old Kingdom to the New Kingdom show that people attempted to bring animals with them to the afterlife that they were attached to, such as dogs, cats, monkeys, even a gazelle, and a horse (TeVelde, 1980).

Animal mummies are a rich and unique source of information for understanding the environmental as well as the religious and cultural history of ancient Egypt. Ikram (2005) mentioned that there are four types of animal mummies:

- Pets were mummified and buried in their owners' tombs, or buried outside of them. Sometimes they had their own sarcophagus or coffin, as well as their own food offerings.

- Victual mummies consisted of funerary food offerings for humans. Meat and poultry, prepared to be consumed, was wrapped up and sometimes placed in individual coffinets or large baskets, and interred with the deceased.

- Sacred animals, believed to possess an aspect or essence of a deity, were worshipped during their lifetime and mummified with pomp upon their deaths.

- Votive mummies were dedicated as offerings at the shrines of specific gods to whom these animals were sacred.

The gazelle mummy in this study was likely a sacred animal mummy (Lurker, 1984).

The gazelle mummy studied was found in a necropolis which included several catacombs used for the burial of gazelle mummies. This necropolis is located in a desert area some three kilometers south of Komir, Esna, Qena, Egypt. It dates to the Late and Greco Roman Periods. Other animals, such as ibises and baboons, were kept in large numbers as cult animals and could be purchased to serve as mummified messengers to the deity. This suggests that gazelles may have been kept for a similar purpose at a temple complex as sacred animals. The mummified gazelles found in the Komir necropolis were wrapped with the limbs tucked under their bellies in a pose reminiscent of the recumbent gazelles in the two and three dimensional depictions of them in Egyptian art. Many of these gazelle mummies were reportedly female (Strandberg, 2009).The gazelle mummy studied belonged to the species Dorcas Sp. (Meier, 2001).

Brier (1994) reported that the majority of mummification techniques used on animals were poor. He also said that this may be due to the fact that Egyptologists Belzoni, Davis, and Ayrton had no interest in mummification; therefore they left no records of the processes used to preserve the animal mummies that they unearthed. Fortunately, there are several Egyptologists that have performed autopsies and investigations on animals mummies to determine the methods used to embalm them (Brier, 1994). Visual examination and radiography conducted on specimens from the Cairo Museum by Ikram (2005) have provided a great deal of information. She proved that some of the animals she studied were mummified in the same manner as upper class humans of the time. Human mummification, in its classic phase, began with extracting the brain from the nose and then filling the cranial cavity with resin. Then a cut was made in the left side of the torso and the lungs, liver, stomach, and intestines were removed by the embalmer.

The body cavity was then filled with natron, incense, and spices, and allowed to desiccate. Once dry, the mummy would be wrapped in bandages and prepared for burial. Other animals were mummified with secondary method of mummification.

The conservation of mummies is a politically and socially sensitive issue (Cassman & Odegaard, 2004). The preservation of a mummy after study involves: (1) Identifying the type of mummification process used and the state of deterioration; (2) Selecting an appropriate method of study; (3) Individualized restoration; and (4) Recommending storage conditions, including environmental and pest protection. Finally, storage conditions should show the respect that each human body deserves, taking into account the laws and beliefs of each nation (Lombardi, 2001).

Deterioration in mummies is caused by several factors, including environmental conditions, physical damage, biological damage or damage caused by previous conservation attempts. Sometimes, these factors occur in isolation, but they can also be present in combination (David, 2001).

Insects are considered one of the most serious factors causing damage to Egyptian mummies. Panagiotakopulu (2001) reported that mummies, both human and animal, were highly susceptible to insect attack. The presence of insects depends on three factors (climate, food and competition with other living organisms) (Hill, 1985). Of the direct effects of climate, perhaps the most important, is that it governs the geographical distribution of insects. Some insects thrive in a temperate climate, others in a tropical one. For most insects there is an optimum climate in which they grow and increase most rapidly. The element or factor in that optimum climate which we can most easily measure is temperature. Humidity and variation of light intensity or photo-periodicity can also be measured, but all the three are so closely bound together that it is difficult to assess the part played by each one, except under controlled condition, as Elton has remarked (Munro, 1966).

The growth of microorganisms in organic materials such as mummies is dependent on the presence of moisture, although, other factors such as temperature should be taken into consideration to understand the biodeterioration mechanism (Valentin, 1996). Many fungal and bacterial species require available moisture for their development on the surface of an object. In this context, scant research has been done to determine the effect of moisture content in a material on the germination of microbial spores to indicate the risk of microbial contamination (Valentín, 2001). A temperature range for the growth of microorganisms is 30°C (Valentin, 2002), this temperature keeps reaction rates in check, specifically the denaturing of collagen, the major constituent of mummy skin (Maekawa, 1998), as high relative humidity (RH) that arrives at 65% or higher aids in decomposition of mummies, although there are species of fungi that depend on a temperature range between 4°C to 35°C without need of moisture (Valentin, 2002). We can find other factors such as pH value which aid in the growth of fungi and bacteria, whereas the fungi prefer acidic environments pH 6 is suitable for growth (Abdel-Maksoud, 1995). High temperatures from internal case lighting and windows can also cause the mummified skin to stiffen and become more susceptible to cracking and chemical breakdown. The chemical destruction of mummified tissue can also occur through exposure to air pollution, often high in large cities and industrial areas. Sulfuric acid can result from sulfur emissions combined with fog. Potentially, sulfuric acid produced in the right atmospheric conditions can break down the proteins of the mummified tissue (Maekawa, 1998 & Meier, 2001).

Progress in research methodology has

produced new examination procedures which result in greater detail in the description of the mummys' external features and in dissections that use highly technical methodology, i.e. historical, pathohistological, and chemical analysis, and sophisticated radiographic techniques. Such investigations make possible a detailed study of mummification techniques and facilitate finding changes in bodies structure (Klys et al., 2001). Some of the identification methods for macrobotanical remains include morphology using light microscopes (Hastorf, 1999). Infrared spectroscopy is also commonly used in archaeological studies. Cotte et al., (2005) listed the applications of infrared spectroscopy for the study of mummies:

- Analyses with FTIR were performed to identify the chemical composition of some fragments taken from the body, bandages and cartonnage wrapping of Egyptian mummies;

- Attenuated total reflection (ATR-FTIR) was used to study thick samples, for example in the analysis of the outer and inner surfaces of pieces of skin taken from the well-known Iceman. Žemaitytė et al., (2006) mentioned that Fourier Transform Infrared Spectroscopy (FTIR) allows one to determine the constitution of wrappings. FTIR was also used in the investigation of archaeological hair from Gravesites at the Home of Samuel Washington (Rowe, 2010). The scan can determine the morphology of fibre and fabric surfaces. Titlbachova & Titlbach (1977) studied Egyptian mummies in Czechoslovakian collections and they found generally good preservation, with the samples resembling modern European populations with significant African admixture. Hrdy (1978) mentioned that ancient Egyptian samples were studied with scanning electron microscopy by Chiarelli et al. (1970/1971), finding significant loss of cuticular scale edges. A specimen of hip bone from a Tyrannosaurus rex, excavated from a ranch in Wyoming over 100 years ago, and thought to be 65 million years old, is shown by scanning electron microscopy to have intact, mummified microscopic collagen fibers and other ultra-structural features within the compact bone (Armitage, 2001). X-ray diffraction has been used to determine components and crystallinity of bone and other associated materials (Robles 2002; Meneghini et al., 2003; Reiche et al., 2003; Fantner et al., 2004; Abdel-Maksoud, 2010).

The conservation of mummified remains involves two procedures. First, it is necessary to store the mummies in a suitable environment, ideally with a relative humidity, of 40-55 percent and a constant temperature of 18-22° C. Secondly, if environmental deterioration has already occurred, then the damage cannot be eradicated thorough environmental control alone and it is necessary to apply other methods to arrest the damage (David, 2001). This study aims to:

1. Describe the deterioration aspects found on the mummy studied;

2. Explain the deterioration mechanisms of the studied mummy resulting from our investigations;

3. Apply some conservation techniques for the treatment and restoration of deteriorated mummy.

2. MATERIALS AND METHODS

2.1 Historical background of the gazelle mummy studied

The mummy studied is located in the Agriculture Museum, Giza, Egypt. It is exhibited in the section of wild animals and domesticated birds. Its Museum Number is 786. The mummy dates back to the Late Period (525-343 B.C). It came from Komir, a village in south Esna, Upper Egypt.

2.2 Visual assessment by digital camera and AutoCAD

To show the changes associated with gazelle mummy, a high-resolution digital

camera image (Kodak Easy Share M1033, 10mp, 3×Optical zoom) was used to create realistic photographic documentation of the aspects of deterioration. The visual observation was used to follow the changes and to explain the deterioration forms.

To show aspects of deterioration for the gazelle mummy, computer graphic documentation was done using (AutoCAD 2007). With CAD, a map of the damage was made, and each face of the mummy was documented.

2.3 Light microscope for the identification of mummy wrappings

The wrappings used with mummy were from plant fibers. For plant identification, a separate sample from the gazelle mummy was taken. A thin section (30-50mμ), which had been prepared at the botany department at Ain Shams University, was examined by light microscopy for details of internal structure and compared with the reference collection kept in the Archarobotany Laboratory, Department Botany, Faculty of Science, Cairo University.

2.4 Isolation and identification of fungi

To identify fungi on the gazelle mummy, some sterilized cotton swab were used to swab different areas where biological damage was visible on the bandages and wrappings of the mummy studied. Czapek-Dox agar medium was used for the isolation of fungi. This medium consists of 3 g $NaNo_3$, 0.5 g KCL, 0.5 g $MgSo_4$, 1 g $K2HPo_4$, 30 g sucrose, 17 g Agal, 1000 ml distilled water, and pH was 5.5. A pure culture from Czapek-Dox agar medium was made. Fungus colonies were identified according to Raper & Fennell, 1965; Barnett & Hunter, 1972; Domsch et al., 1980; Stevens, 1981. The isolation and identification of fungi were achieved at the Micro Analytical Center, Faculty of Science, Cairo University, Egypt.

2.5 Investigation of the surface morphology by SEM

A scanning electron microscope JEOL-JSM-5400LV was used to observe the surface morphology. The fine gold coating (JEOL-JFC-1100E) was used. Lenin, bandages and hair of the mummy studied were investigated.

2.6 Fourier transform infrared spectroscopy (FTIR)

Fourier transform infrared attenuated total reflection (FTIR-ATR) has been extensively used on linen and hair samples to investigate absorption and reactions on surfaces. This method of analysis has been used in accordance with Jadoul et al., 1996; Pouliot et al., 1999; Xie et al, 2002; Velkova & Lafleur, 2002; Liao et al, 2006; Dias et al., 2008; Russeau et al., 2009.

A significant advantage of ATR technique is that the archaeological samples require no preparation, thereby minimizing possible damage (Bernard, 2007). Infra-red spectra were obtained using a FTIR spectroscopy (JASCO-ATR-FT/IR-6100).

For the archaeological bone sample, it was ground to a fine powder with an agate mortar and pestle. FTIR grade potassium bromide (97-99 mg) was ground to a fine powder in a separate agate mortar and pestle. The two powders (100 mg total) were then combined and mixed with a spatula. An additional 100 mg of KBr was ground into a fine powder, and then used to obtain background spectra. The sample was transferred into a sample cup to overflowing, and a cover slip was dragged across the top of the cup to remove excess powder and smoothed the sample surface in order to maintain uniform distribution of particle size. Each sample was then mixed with KBr and placed in a DRIFT cell. This method of analysis gives information on the composition and crystalline of the bone mineral, and at the same time gives an indication of the behavior of the protein

materials in bone (Abdel-Maksoud, 2010). Spectra were assigned for new and archaeological samples. Infrared spectra were obtained using a Fourier transform infrared spectroscopy (JASCO-FT/IR-6100).

2.7 Amino acid analysis

Two samples weighing 0.8 mg were taken from the gazelle mummy's bone and from a new Gazelle bone, which was used as a reference. They were both placed into a hydrolysis tube. 1ml of 6NHCl was added (HCl Supra pure from Merck). The solution was frozen using a mixture of dry ice/ethanol and the tube was evacuated using a vacuum pump [6.5Pa (0.01 mbar)]. Intermediate flushing with oxygen-free nitrogen was executed. The hydrolysis tube was then closed by melting the glass with a gas-burner. The hydrolysis tubes were placed in an oven with a uniform temperature distribution of 110°C for 12, 24, 36, or 72 hrs. In order to create reproducible hydrolysis conditions, the samples were hydrolyzed in an air circulation oven. The tubes were later cooled in an ice-bath. The solution was then centrifuged in order to precipitate insoluble components. The resulting supernatant was evaporated at approximately 40°C in a rotary evaporator, the remaining were dissolved in approximately 1ml of dist. water and evaporated once again to remove traces of acid. The sample was dissolved in 1–2 ml of the sample diluting buffer after which it was ready for analysis. The instrument used was Eppendor- Germany (LC3000 Amino Acid Analyzer). The condition of the instrument was: flow rate: 0.2 ml/min, pressure of buffer form 0 to 50 bar, of reagent to 0-150 bar and reaction temperature was 123°C (according to Abdel-Maksoud, 2011).

2.8 X-ray diffraction for the measurement of bone crystallinity:

X-ray powder diffraction data were collected on an X-ray diffract meter 6000 (Shimadzu, Japan) using Cu Kα radiation from a tube operated at 45kv and 35mA. The two samples studied (new and archaeological samples) were measured from 0° to 65° 2θ to obtain a diffraction pattern. The crystalline index of new and archaeological samples was determined using x-ray diffraction (XRD) on the basis of the full width of half maximum (FWHM) of the apatite diffraction 002 (Abdel-Maksoud, 2010).

3. CONSERVATION TECHNIQUES USED

3.1. Cleaning processes

Mechanical and chemical cleaning processes for all Components of the mummy (wrappings, bandages hair and etc.) were applied in accordance with Gänsicke et al., 2003 and Farrell et al., 2006.

3.2. Consolidation

The consolidation process by using Klucel G (Hydroxypropylcellulose) 1% in ethyl alcohol was applied for Linen, hair and papyrus in accordance with Abdel-Kareem (2000).

3.3. Completion process

The authors used a new paste for the completion of some sections on different parts of the mummy studied. The paste used consisted of beeswax, shellac, sawdust, turpentine (3:2:1:1/2 respectively), 6ml of tea tree oil diluted in ethanol (1600 mg/gm), and a mixture of black (magnetite, Fe_3O_4) and red iron oxides (hematite, Fe_2O_3) were added to match the natural surface tones of the mummy.

3.4. Reconnecting loose part of the gazelle's leg

The authors used galvanized wire for reconnecting a loose part of mummy's leg.

3.5. The display of the gazelle mummy

Plexiglass [polymethyl methacrylate (PMMA)] and wooden base were used for making the stand of the mummy.

4. RESULTS AND DISCUSSIONS

4.1. Visual assessment by digital camera and AutoCAD

The gazelle mummy (Figs 1 and 2) being studied contains several materials, which can be divided into two parts, first part contains the constituent materials of gazelle body (hair, tissue, bones), while the second part contains the mummification materials (resins, wrappings of papyrus and linen). Through the naked eye observation, it was found that all of these items had been damaged to varying degrees which can be summarized in the table 1.

4.2. Light microscope for the identification of mummy wrappings

Table 1: Visual assessment of gazelle mummy

No.	Side		Observation
1	Right Side (Fig. 1A)	Forehead Area	- Missing in the outer layers of the papyrus wrappings; - There were some white spots, which may reflect micro-organisms infestation; - The presence of some dust stuck to the linen was recorded; - Dryness in the linen bandages was noticed.
		Right Horn and Linen Bandages of the Right Ear	- The presence of white spots on one of the two horns, and a change in its color as a result of dust and the likelihood of changes in its composition were observed; - Degradation of linen used in ear wrapping, and dust adhered to the linen were noticed.
		Neck	- The presence of ubiquitous white spots; - Dryness and gaps in the linen bandages; - The presence of dust adhered to the linen.
		Abdomen and Back Areas	- Gaps in many parts of linen bandages; - Dryness in the linen bandages which are covered with very dark resinous material. The dark color of the linen bandages may be due to the result of oxidation or hydration of the resin; - Lost hairs in areas not covered with linen; - Damage to linen bandages. This may due to the reaction between the iron wire, used for installation of the mummy on the wooden base, and the linen bandages.
		Right Legs	- Broken front leg of mummy. Resinous substance was found on the broken area. The resin may have been deposited previously in improper conservation.

2	Left Side (Fig. 1B)	Forehead Area	- Missing some papyrus wrappings from the face area; - The presence of dust on the papyrus wrappings; - Tears, dust and dryness on the linen bandages.
		Left Horn and Left Ear Wrapping	- Section of the upper part of horn missing and change in horn color as a result of dust. - Some linen degradation on ear bandages; - Dust adhered to linen was also noticed.
		Neck	- Dry and missing linen bandages; - Dust adhered to linen; - Gaps in papyrus wrappings.
		Abdomen and Back Areas	- Missing some parts of the linen bandages, but missing portion was less than that on the right side; - Tears and dryness on the linen bandages; - Change in linen color, tending towards dark brown or black; - Damage to linen bandages. This may due to the reaction between iron wires and the linen bandages (as mentioned above in the description of the right side).
		Left Leg Area	- Broken and missing bones and tissues of of the foreleg; - Broken back leg; - Degraded linen under the foreleg. - Damage to the lower part of mummy from the iron column used in the installation process.
3	Front Side (Fig. 1C)	Face Area	- Missing outer layers of the papyrus wrappings; - The presence of some dust adhered to the linen.
		Neck	- Missing and dry linen bandages; - Missing hairs and crack on the neck's tissue.
4	Back Side (Fig. 1D	Head Area	- Missing linen and dust on the upper part of head; - Degradation of the linen bandages.
		Horns and Ears	- Missing papyrus wrappings on the right ear; - The presence of a large white spot which may be attributed to a fungal infestation; - The presence of dust adhered to the linen.

		Neck	- Missing outer layer of papyrus wrapping and degradation of the linen bandages.
		Abdomen and Back Area	- Missing or dry linen bandages, stained with dust; - Some holes and bores in the backbone, which may be attributed to the insect damage; Missing tail and damage to the inner part, this may also be attributed to the insect damage.
5	Upper Side (Fig. 1E)	Head Area	- Dust adhered to linen bandages and papyrus wrappings; - Damage to the bandages on the ears; - Missing horns.
		Backbone and Back Area	- Dry and missing linen bandages; - Missing hairs and tissues on the spine.
6	Lower Side (Fig. 1F)		- Missing, dry , degraded and torn linen bandages; - Fungal infestation; - Missing tissue on the abdomen; - Degradation of the linen bandages on the mummy's leg; - Dry bandages on the back.

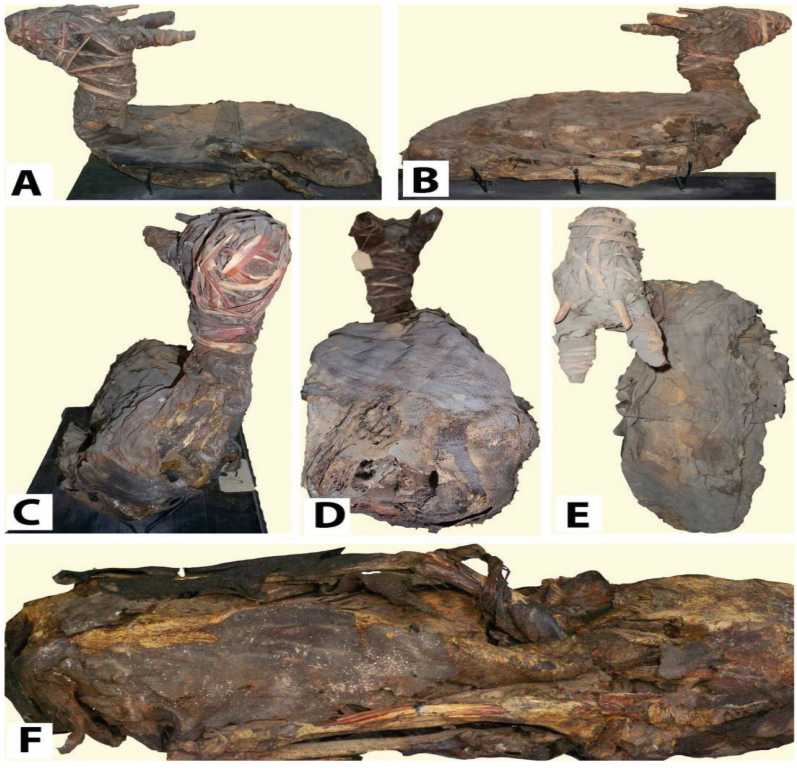

Figure 1.Gazelle mummy before conservation: (A) Right side; (B) Left side; (C) Front side; (D) Back side; (E) Upper side; Lower side

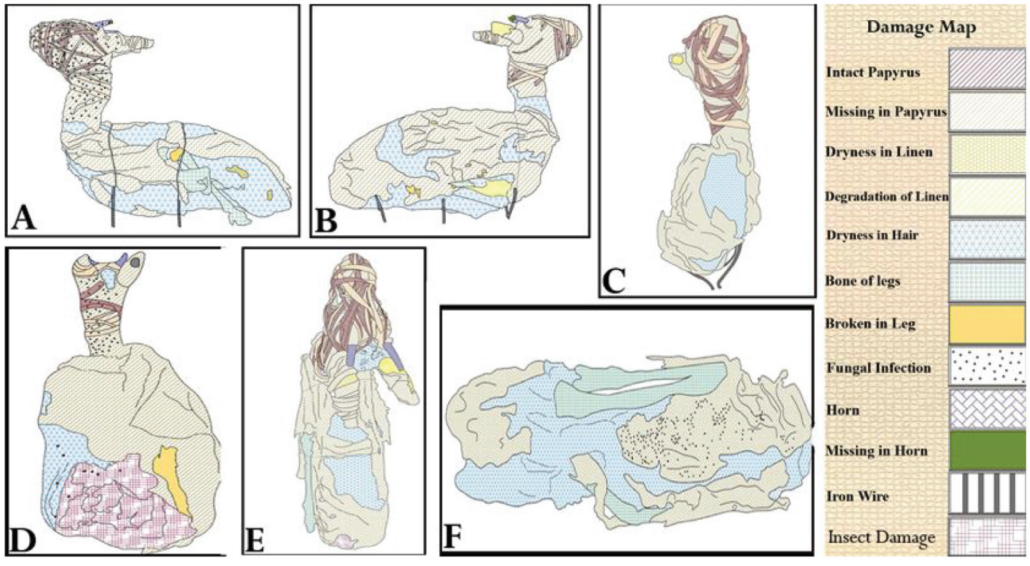

Figure 2.AutoCAD for documentation of deterioration aspects: (A) Right side; (B) Left side; (C) Front side; (D) Back side; (E) Upper side; (F) Lower side.

The mummy wrappings were identified as *Cyperus papyrus* L. (Papyrus). The results obtained in (Fig. 3) showed thatthe epidermis is formed of ordinary thick-walled epiderminal cells. Below are patches of chlorenchyma tissue alternating with strands of fibers. The ground tissue is differentiated into a narrow peripheral zone formed of several layers of radially elongated chlorenchyma cells and small reduced vascular bundles, and a large inner layer made up of highly lacunateaerenchyma with 3-armed cells and collatral vascular bundles surrounded by a sheath of 2-3 thick-walled lignified cells. The parenchyma cells are withered especially at the middle.

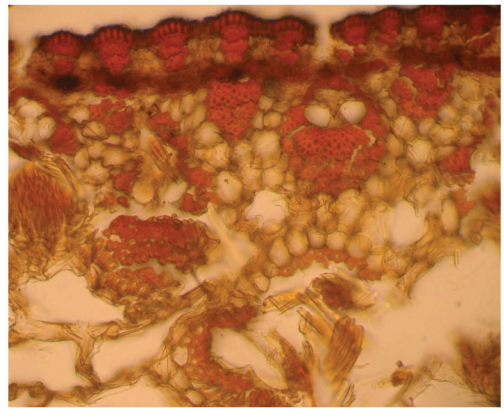

Figure 3. Mummy wrappings identified as *Cyperus papyrus* L. (Papyrus) by light microscope.

4.3. Microbiological investigation

The most dominant fungi isolated from the mummy studied are shown in the table 2. The identified fungi belong to two genera, Ascomycotina and Zygomycotina. Infestations of fungi, particularly *Rhizopus sp.*, caused the white spots found on the linen bandages. The percentage (%) of identified fungi were:

(25%), Aspergillus fumigates (18.75%), Aspergillus niger, Pencillium chrysogenum, Rhizopus arrhizus and Rhizopus nigricans (12.5%) and Aspergillus flavus (6.25%).

Biodeterioration is a significant factor in the decomposition of human and animal bodies, because fungi grow and feed on many of the constituent products, such as protein, fats, starch and cellulose (Elnaggar et al., 2010). The results of our study were paralleled by several similar studies on archaeological material. Arya et al., (2001) isolated twenty-two viable species of fungi

Table 2. Identified fungi isolated from linen sample

Fungi isolated	Colonies	Percentage (%)
Ascomycotina		
Aspergillusniger	**2**	**12.5**
Aspergillus flavus	**1**	**6.25**
Aspergillus fumigates	**3**	**18.75**
Pencillium egyptiacum	**4**	**25**
Pencillium chrysogenum	**2**	**12.5**
Zygomycotina		
Rhizopus arrhizus	**2**	**12.5**
Rhizopus nigricans	**2**	**12.5**

belonging to 17 genera in May 2000 from the indoor air of the Egypto-Babylonian Gallery by the gravity fall method. The air and dust of the mummy chamber revealed six different fungi. The mycoflora was dominated by different Aspergilli. Isolated from the first toe of the right leg of an 1.54 m long Egyptian mummy was *Emericellanivea* (Wiley & Simmons). This fungus caused white powdery patches on the toes of the mummy. Valentín (2001) stated that among the types of fungi found in Spanish museums, archives and libraries are *Aspergillu sniger, Aspergillus flavus, Aspergillus fumigates, Penicillium chrysogenum, Rhizopus nigricans.* Valentín (2003) reported that *Penicillium and Aspegilluss* trains are harmful to textiles because they have a high level of cellulolytic activity and grow in materials with a moisture content of 7- 8%. David (2008) mentioned that fungi of various types are often seen in ancient tissues as a result of poor storage of the specimen. The fungus produces oxalic acid as another metabolic byproduct. The acid acts in a similar way to the acids in the decalcification process but in this case, instead of producing a soluble salt, the oxalic acid produces an insoluble calcium oxalate compound that forms clusters of crystals on bone.

Zielińska-Jankiewicz et al., (2008) studied the species accounting for mycological contamination of the library, archive and museum collections, which include *Aspergillus, Penicillium, Geotrichum, Alternaria, Cladosporium, Mucor, Rhizopus, Trichoderma, Fusarium.* Arroyo (2009) found among the types ancient proteineous materials are *Aspergillus and Penicillium.* Valentín (2010) stated that 16 historical buildings located in different climatic regions of Spain were analyzed to detect cellulose and protein-degrading microorganisms. Non-destructive and surface samples were taken from objects made of cellulose (paper, cardboard and textiles) and protein materials (parchment, leather, mummies and silk textiles). *Aspergillus flavus, A. fumigatus, A. niger and Rhizopus nigricans* were among the identified fungi.

4.4. Scanning electron microscope (SEM)

4.4.1. Hair sample

Scanning electron microscopy was used to determine the external condition of individual fibers. Resin-covered fiber was observed (Fig. 4A and 4B) and some cracks in the resin layer were noticed (Fig. 4C). Variable microbe degradation of the gazelle

hair was observed (Fig. 4D). The presence of tunnels within the degraded hair, similar to those found by Wilson et al. (2007) indicates that much of this damage was caused by fungi. The presence of holes and erosion of the cortex characteristic of fungal tunneling highlighted the potentially aggressive nature of the depositional environment (Wilson et al., 2001). Accumulated dusts were also observed. Some cracks in the fiber structure and on the surface were noticed (Fig. 4C and 4D).

4.4.2. Papyrus sample

The scanning electron microscope can be a useful tool for papyrus investigation. The wave pattern of cut papyrus was noticed (Fig. 4E). The SEM showed serious tears, holes and the separation of cellulose fibers. The outer surface of the papyrus showed a covering of starch and fissures along a vascular bundle (Fig. 4F). Resin-covered papyrus fibers were observed. Pierced cell tissue on the inside of the papyrus was shown (Fig. 4H). Some dust was also observed on and inside the fibers (Fig. 4G, H).

4.4.3. Textile sample

The scanning electron microscope is able to physically examine virtually any textile material without any special preparation or conductive coating (Wei et al., 2004).By SEM we can investigate the morphology of fiber and fabric surfaces. Our textile sample was composed only of friable brown thread in an open plain weave (Fig. 4I). The linen fiber consisted of coarse material, which proves the low quality of the linen. Holes and cracks in the resin layer can be observed (Fig. 4J). A thick layer of dust (Fig. 4K) and a layer of resin covered linen fibers were also noticed (Fig. 4L).

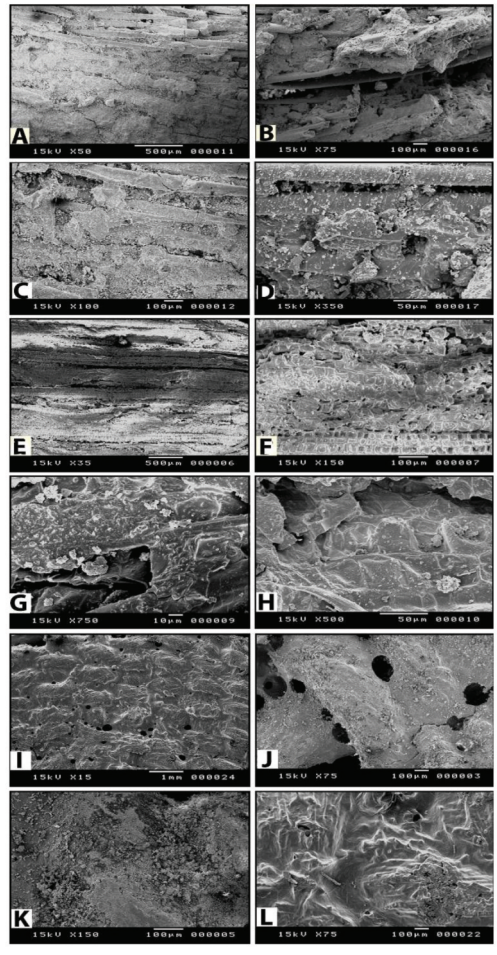

Figure 4.(A-D)SEM micrographs show damage to the mummy's hair: (A) Dust and resin covering the hair surface; (B) Resin within the hair fibers; (C) Accumulated dust and cracks in the fiber structure; (D) Accumulated dust, holes and erosion of the hair; (E-H) SEM images for a sample of the papyrus mummy wrapping; (E) Wave pattern of the cut papyrus; (F) Starch covering and fissures along a vascular bundle; (G) Dust on resin covered papyrus fibers; (H) Pierced cell tissue on the inside of the papyrus; (I-L) SEM images for the sample of linen mummy wrapping; (I) Friable thread in an open plain weave; (J) Holes and cracks in the resin layer; (K) Thick layer of dust; (L) Resin covered linen fiber.

4.5. Fourier transform infrared spectroscopy (FTIR):

4.5.1. Bone sample

The results of this section were explained and discussed in accordance with

Abdel-Maksoud (2010). It is clear (Fig. 5A) that the band at 3422.06 cm^{-1} in the new sample (control) assigned to a broad band represents (OH) hydroxyl stretching due to intermolecular hydrogen bonding of the hydroxyl group. This band includes multiple bands made up of multiple N-H groups (its primary amides), both in the solid state and in the presence of hydrogen bonding. In the archaeological sample, this band shifted to a higher position (3429.78 cm^{-1}). The C-H stretching vibrations occur in the region (2924.52-2926.45) stretching of aliphatic groups, and they were found in two samples that were studied. The position of the band in the archaeological sample was very close to that of the band of the new sample. The bands between 3422.06 cm^{-1} and 2924.52 cm^{-1} in the samples are protein characteristics, and the increase or decrease of these bands may give an indication of the expansion or contraction of the protein areas. Collagen exhibits a series of absorptions from 1656.55 cm^{-1} to 1241.93 cm^{-1}. Band at 1656.55 cm^{-1} (C=O stretching) in the new sample is assigned to amide I and the position of this band is decreased in the archaeological sample (1641.13 cm^{-1}). The increasing or decreasing of C=O is dependent on the physical state of the sample. In the solid state, the frequency of the vibration is slightly decreased. The presence of hydrogen bonding is an important contributing factor to this decrease in frequency. The bands at 1562.06 cm^{-1} (NH, CN stretching) in the new sample are assigned to amide II. Amide II disappeared in the archaeological sample. The band at 1241.93 cm^{-1} is assigned to amide III which involves C-N stretching and N-H bending. The wave-number of these peaks depends on the secondary structure of the protein (e.g., α-helix, β-sheet, β-turn, random coil). The position of this band increased in the archaeological sample (1243.86).

4.5.2. Hair sample

The examination of these spectra allowed the researcher to confirm the presence of frequencies characteristic to keratin and the changes in band intensity in the archaeological sample. Several important points were obtained from ATR-FTIR analysis of the samples (Fig. 5B):

- According to Espinoza et al. (2008), the region (1200 to 1000 cm^{-1}) is associated with vibrations of the sulphur-oxygen groups of keratin. The results proved the presence of sulphur-oxygen groups in the two samples. The degradation in the archaeological sample compared to the control sample was recorded.

- The peptide bond is the most abundant bond within a keratin protein (Panayiotou, 2004). The spectra of amide I, ν(CONH), the amide II, $\delta(CH_2)$ and the amide III, δ(NH) bands were examined. The spectral analysis indicated significant, observable keratin degradation of archaeological hair sample.

- Oxidation of the amino acid cystine to cysteic acid can occur in hair, resulting in an increase of the S=O stretching absorbance (Robotham, www.thermo.com). Hair fibers analyzed by ATR-FTIR clearly show the difference between new and archaeological samples. Fig. 5B shows the region between 1400 and 900 cm^{-1}, revealing the spectral differences due to the oxidation of cystine to cysteic acid.

4.5.3. Textile sample

The infrared spectra of new and archaeological linen samples (Fig. 5C) were recorded from 4000-400 cm^{-1}. The results showed that there are changes in the IR spectra of the archaeological sample compared to the spectra of the control sample. By comparing the results, it is evident that there are significant spectral changes in the region from 1750-1600 cm^{-1} for the archaeological sample. The region from 1750-1600 cm^{-1} proved the most convenient for monitoring cellulose

degradation. It was confirmed that archaeological linen cellulose involves carbonyl and carboxylate group functions, which can be monitored by the infrared reflection at 1750-1600 cm^{-1} with FTIR Spectroscopy.

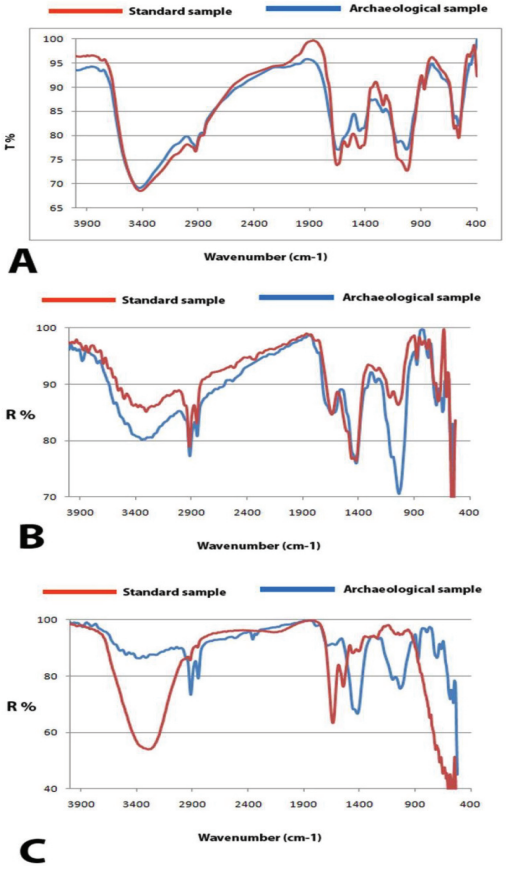

Figure 5. FTIR analysis: (A) FTIR spectra of the modern and archaeological bone samples; (B) FTIR spectra of the modern and archaeological hair samples; (C) FTIR spectra of the modern and archaeological textile samples.

4.6. Amino Acid Analysis for Bone sample

The results of the amino acid analysis of the sample taken from both the new reference bone sample and the archaeological bone sample (shown in Fig. 6A and 6B) revealed that there was less of the basic amino acid lysine in the mummy (9.6%) than in the reference sample (28.74%). The value of the basic amino acid arginine in the archaeological sample was 153.60% while its value in the reference sample was 357.83%. A similar trend was noted for the basic amino acid histidine. Its value was 0.40% for the mummy bone and was 51.92% in the reference bone.

It can be explained by the fact that the oxidative decomposition of the side chains of amino acids forms ammonium ($NH4^+$). The basic amino acids lysine and arginine are particularly sensitive to oxidation and our results reflected this. The archaeological bone sample showed that ammonium content was 73.70% and the value was absent in the new reference bone sample.

The acidic condition of the archaeological bone sample may lower the value of the basic amino acids and increase the value of ammonium ($NH4^+$). This also indicated that acid hydrolysis may also have occurred for the archaeological bone sample.

In was noticed that with an increase in $NH4^+$, there was a clear tendency for lower

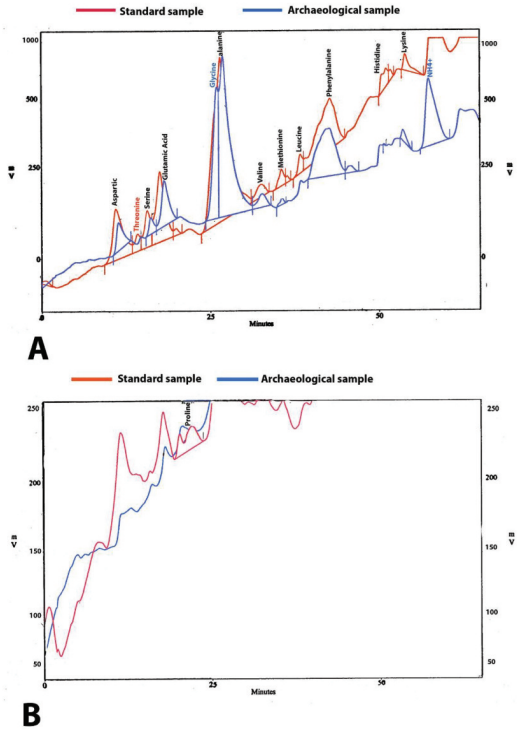

Figure 6. (A) Identified amino acids of bone of both the standard and archaeological; (B) Identified proline of standard and archaeological samples.

value of serine (7.8%) in the archaeological sample and 37.8% in the reference sample, and threonine, which was absent in the archaeological sample and the value of which was 19.4% in the new sample.

The lower value of aspartic acid in the archaeological sample (25.92%) than the new sample (119.73%) indicated the increase of hydrolysis in the archaeological bone sample.

4.7. X-Ray Diffraction (XRD) For Bone Sample

The main aim of using XRD in this study is to measure the crystallinity index of bone (Fig. 7). Full Width at Half Maximum (FWHM) measurements were made on the apatite d002 peak. This measurement has proven useful as a measure of apatite crystallinity. Farlow and Argast (2006) have objected to this approach due to the possible interference of quartz. However, this method of measurement is most commonly used. The samples examined generally present characteristic X-ray diffraction patterns typical of poorly crystalline hydroxyapatite, namely, that there is little difference between the new sample and the archaeological sample. The crystallinity index of the new sample was 0.30 mm. The crystallinity of the peak 002 of the archaeological sample was 0.11cm. The data showed that the width at half maximum of the peak 002 of the new sample was more than that of the archaeological sample. This means that the archaeological sample was more crystalline than the new sample. This also indicates that the archaeological sample was affected by its burial environment and was dryer than the new sample. These results were confirmed by Abdel-Maksoud (2010), Abdel-Maksoud and Abdel-Hady (2011) who reported that archaeological bones have higher crystallinity and sharper X-ray diffraction patterns than new samples.

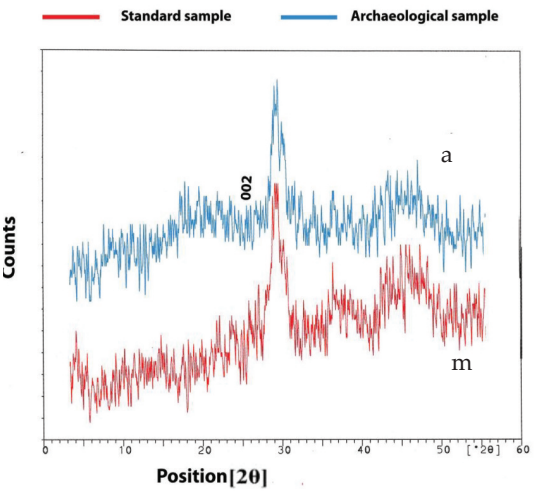

Figure 7. XRD diagrams of modern (lower) and archaeological (uper) bone samples.

5. CONSERVATION

5.1. Cleaning processes

5.1.1. Mechanical cleaning

The purpose of mechanical cleaning of the mummy studied is to:

1. Reduce the potential for damage to the mummy by removing foreign material which may be abrasive, acidic, hygroscopic, or degrading;

2. Reveal the decorative bandages and wrappings of the mummy by removing surface dirt when it interferes with the visibility of the imagery or information.

It should be noticed that a decision must be made to balance the probable care of each material of the mummy against the possible problems related to surface cleaning.

Due to the dryness of the mummy's materials (linen bandages, papyrus wrappings, hair and tissue), mechanical cleaning was done carefully by using a soft brush. This was suggested by Gänsicke et al., (2003) who recommended the use of a soft camel-hair or similar small soft brushes for removing surface dust and dirt. Farrell et al., (2006) also used soft brushes for the cleaning of cartonnage mummy surface. The cleaning process of the mummy studied was done in several steps, every

face was brushed individually (right, left, front, back, upper and bottom). The removal of dust on the surface of the above mentioned materials was done by using soft brushes. Special care was taken with fragile and loose fibers. Unfortunately, the cleaning test results for the resinous substance, which was evidently from previous conservation, showed that it could not be removed without damaging the mummy's bandages and hair. Therefore, the cleaning had to be stopped.

Due to the significant use of resin and the bad state of preservation of gazelle mummy, dust was adhered to the materials mentioned above, and was difficult to remove by mechanical method.

5.1.2. Chemical cleaning

One of the key standards of conservation is reversibility: anything done to preserve a piece should be able to be undone with minimal damage to the piece itself. Chemical cleaning is not reversible, and so it should be used only when absolutely necessary. Before chemical cleaning several things should be taken into account to determine both the best treatment for that particular combination of object and soil, and to ascertain whether the object is able to be cleaned, or may sustain damage during the process: chemical composition of the object, degree of deterioration, type of materials to be removed and the type of cleaner used.

Chemical treatment was needed for extremely dirty linen, hair and papyrus. Chemical cleaning was performed by using alcohol and distilled water (1:1/2) followed by using alcohol alone for evaporation of water residue.

According to Gänsicke et al. (2003) more adherent dirt should be removed using water or alcohol and a soft brush. Cleaning was performed by gently rolling swabs across the surface. The surface tolerated aqueous cleaning with moderately damp swabs. The black resinous substance on the above-mentioned materials was not removed. Adhesive particles and tape were left if they were in fragile areas. After cleaning, sufficient time was allowed for the mummy to dry before continuing treatment. The mummy's hair was cleaned carefully according to a method proposed by Abdel-Maksoud (1995), who stated that other than removal of earth and soil, fabric and hair did not require a great deal of cleaning. According to Gänsicke et al. (2003), horn does not need more cleaning than a rinse with lukewarm water, but he warned against insect attack. So the horns were cleaned using water and alcohol, then treated with tea tree oil as resistance materials.

5.2. Consolidation

Consolidation is considered one of the most important processes in our case study. Conventional stitching techniques cannot be used with linen wrapping because the needle and sewing thread may break the dry and fragile linen threads. For linen, hair and papyrus consolidation, Klucel G (Hydroxypropylcellulose) 1% in ethyl alcohol was used. Cosolidant was applied using a brush. Klucel G was recommended by Abdel-Kareem (2000), who mentioned that linen samples treated with Klucel G showed the best reduction in growth of *Aspergillus nidulans, Aspergillus terrus,Penicillium asperum, Trichoderma viride and Penicillium funiculosum*. It has been used successfully in water/alcohol solutions to consolidate ethnographic materials which have a matte surface. Klucel G varies in strength, according to grade and concentration. Klucel G in low percentage solutions can be brushed on local areas needing consolidation.

5.3. Completion process

There are some missing sections on different parts of the mummy studied.

There was a hole on the mummy's back (Fig. 8A), pits in the backbone and neck, and a crack in the neck. It should be noted that largest missing section was on the back of the mummy. Insects had played the primary role in this deterioration. The missing sections were weakened areas and had to be treated.

Before the completion of missing area, disinfection by the use of Tea tree oil *(Melaleuca alternifolia)* diluted in ethanol (Fig. 8B). Completion is the proper process for the treatment of this type of deterioration. The small missing areas were filled with a paste to stop the holes from growing. The paste consisted of beeswax, shellac, sawdust, turpentine (3:2:1:1/2 respectively), 6ml of tea tree oil diluted in ethanol (1600 mg/gm), and a mixture of black (magnetite, Fe_3O_4) and red iron oxides (hematite, Fe_2O_3). On the back, the missing parts were large and could not be filled with the paste because it would be too heavy. The authors used linen bandages soaked in gum Arabic and tea tree oil to fill the inner part of the hole (Fig. 8C) and coated the outside with the paste (Fig. 8D_F).

It should be noted that tea tree oil was used in the paste because of its effectiveness against larvae of leather beetle (Elamin 2011). Tea tree oil *(Melaleuca alternifolia)* ranges from colorless to pale yellow. The most active compounds in this oil are terpinen-4-ol, terpinene, 1,8-cineole and terpinolene. The International Standards Organization, ISO 4730, mandates a minimum concentration of 30% for terpinen-4-ol and a maximum concentration of 1,8- cineole of 15% in the oil. It is considered to have some of the strongest natural antiseptic / antifungal properties in the world (Joshi et al., 2009; Tripathi et al., 2009).

The patched areas were then painted with pigments that matched the natural surface tones of the mummy. The paste was applied using different sizeed metallic rifflers and cone tools.

5.4. Reconnecting loose part of the gazelle's leg

A loose part of mummy's leg was reconnected using galvanized wire. This was done without making any holes in the leg. The repair was needed due to a severe weakness that appeared through analysis.

5.5. The display of the gazelle mummy

There is no absolute rule for the display of mummies. There are guidelines, but also an ongoing debate. It was indicated that many museums now have policies on the display of mummies:

• All such displays should be designed so that the mummies are accompanied by an explanatory interpretation that places them in an historic context. Display of archaeological remains for aesthetic or artistic purposes alone will not be permitted.

• Where human remains are displayed in the museum, there will be a notice outside the relevant display space alerting visitors to the presence of human remains.

The following steps were done for the display of the gazelle mummy:

- Plexiglass [polymethyl methacrylate (PMMA)] was the material used for making the stand. It was preferred because of its easy handling and processing, and low cost.

- Measurements were taken of the three different lower parts of the mummy (front, center and back);

- Three semi-circular pieces were made to fit these measurements;

- Support from the same material (Plexiglas) was made for each piece;

- Each support was integrated thermally with the semi-circular pieces;

- Part of the plexiglas was made into a semi-circular shape and installed on the front support.

- Three compact pieces with supports were installed on a single wooden base;

- The gazelle mummy was carried carefully and put on the stand (Fig. 8G).

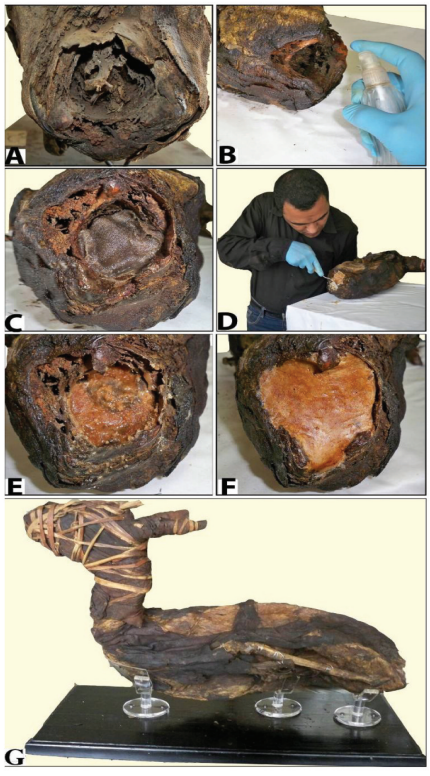

Figure 8.Completion process for the back area: (A) Before treatment; (B) Sterilization by tea tree oil; (C) After placement of linen soaked in a mixture of gum Arabic and tea tree oil; (D-E) During completion; (F) After completion; (G) Gazelle mummy on display.

6. CONCLUSIONS

Several aspects of deterioration were identified through visual assessment, photographic and AutoCAD documentation. All aspects of deterioration indicated that the mummy suffers from deterioration. Papyrus wrappings were identified by light microscope as *Cyperus papyrus* L. Papyrus wrappings showed that the parenchyma cells were withered, especially at their centers. The dominant fungi isolated from the mummy and identified were different types from Aspergillus sp., Pencillium sp. and Rhizopus sp.

An investigation using a scanning electron microscope revealed several aspects of deterioration (e.g. cracks, tears, holes and etc) on the investigated samples (hair, papyrus and textile).

The amino acid analysis showed decreasing levels of lysine, arginine and histidine in the archaeological sample, which indicated oxidation breakdown. The high value of $NH4^{+}$ and decrease in the aspartic acid of the archaeological sample indicated the presence of hydrolysis breakdown.

The results of the bone analysis by FTIR showed that there was degradation in the collagen, since the loss of amides was noticed in the archaeological sample. For hair samples, the presence of sulphur-oxygen groups in the new and archaeological samples was found. Degradation of amides in the archaeological sample compared to the new sample was observed. By recording the amides (I, II and III), the degradation of the archaeological sample compared to the new sample was recorded. The spectral analysis of amide I, ν(CONH), the amide II, $\delta(CH_2)$ and the amide III, δ(NH) band showed significant, observable keratin degradation of the archaeological hair sample. The region between 1400 and 900 cm^{-1} revealed the spectral differences which may be due to the oxidation of cystine to cysteic acid. FTIR results showed that there are significant spectral changes in carbonyl and carboxylate group functions (1750-1600 cm^{-1}) for the archaeological linen sample.

The results of XRD analysis of the bone proved that there is a little difference between the new sample and the archaeological sample. The data showed that the width at half maximum of the peak 002 of the new sample was more than that for the archaeological sample. This means that the archaeological sample was more crystalline than the new sample. This also indicates that the archaeological sample was affected by its burial environment and was dryer than the new sample.

The treatment and conservation processes of the gazelle mummy proved the effectiveness of soft brushes for removing

surface dust and dirt. Chemical cleaning was performed using alcohol and distilled water (1:1/2). These materials yielded significant results in the cleaning process. Consolidation is considered one of the most important processes in our case study. Klucel G (Hydroxypropylcellulose) 1% in Ethyl alcohol was recommended for its ability to consolidate materials which have a matte surface and its effectiveness against fungal infection. The paste used in the completion of missed parts in the gazelle mummy studied consisting of beeswax, shellac, sawdust, turpentine (3:2:1:1/2 respectively), 6ml of tea tree oil diluted in ethanol (1600 mg/gm), and a pigment was also added to give the paste tone of the mummy color, yielded significant results in filling cracks and the missing part on the mummy's back. It can be also added that all the conservation techniques applied reveal the aesthetic value of the mummy studied.

REFERENCES

Abdel-Kareem, O.M.A., (2000) Microbiological Studies to Evaluate Polymers and Resins Used in Consolidation of Ancient Egyptian Linen Textiles, *Czasopismo Techniczne* 1A, 202-211.

Abdel-Maksoud, G., Abdel-Hady, M., (2011) Effect of Burial Environment on Crocodile Bones from Hawara Excavation, Fayoum, Egypt, *Journal of Cultural Heritage* 12/ 2, 180-189.

Abdel-Maksoud, G., (2010) Comparison between the Properties of "Accelerated-Aged" Bones and Archaeological Bones, *Mediterranean Archaeology and Archaeometry* 10/1, 89-112.

Abdel-Maksoud, G., (2011) Analysis and Conservation of an Eighteenth/Nineteenth Century Vegetable-Tanned Parchment Manuscript, *Journal of Leather Technologists and Chemists* 95/2, 47-58.

Abdel-Maksoud, G., (1995) *Experimental and applied study for treatment and conservation of mummies with application on an ancient mummy,* Master Thesis, Conservation Department, Faculty of Archaeology, Cairo, 77.

Armitage, K., (2001) Scanning Electron Microscope Study of Mummified Collagen Fibers in Fossil Tyrannosaurus rex Bone, *CRSQ* 38/ 2, 61-66.

Arroyo, I., (2009) The Role of Fungi in the Deterioration of Movable and Immovable Cultural Heritage, *e-conservation magazine* 9, 40-50.

Arya, A., Shah, A.R., Sadasivan, S., (2001) Indoor Aeromycoflora of Baroda Museum and Deterioration of Egyptian Mummy, *Current Science* 81/7, 793-799.

Barnett, H.L., Hunter, B.B., (1972) *Illustrated Genera of Imperfect Fungi*, 3rd Ed, Burgess puplishing Co., Minneopolis, Minnesota.

Bernard, G., Auger, M., Soucy, J., Pouliot, R., (2007) Physical Characterization of the Stratum Corneum of an In Vitro Psoriatic Skin Model by ATR-FTIR and Raman Spectroscopies, *Biochimica et Biophysica Acta* 1770, 1317–1323.

Brier, B., (1994), *Egyptian Mummies, Unraveling the Secrets of an Ancient Art,* William Marrow and Company,Inc., New Yourk , 208-239.

Cassman V., Odegaard N., (2004) Human Remains and the Conservator's Role, *Studies in Conservation* 49/4, 271-282.

Cotte, M., Walter, Ph., Tsoucaris, G., Dumas P., (2005) Studying skin of an Egyptian mummy by infrared microscopy, *Vibrational Spectroscopy* 38, 159–167

David, A.R., (2001) Benefits and Disadvantages of Some Conservation Treatments for Egyptian Mummies, *Chungará (Arica)* 33/1 Arica ene. versión On-line.

David, AR., (2008) *Egyptian Mummies and Modern Science*, Cambridge University Press, London, 77, 78.

Dias, M., Naik, A., Guy, R.H., Hadgraft, J., Lane, M.E., (2008) In Vivo Infrared Spectroscopy Studies of Alkanol Effects on Human Skin, *European Journal of Pharmaceutics and Biopharmaceutics* 69, 1171–1175.

Domsch, K.H., Gams W., Anderson T.H. (1980) *Compendium of Soil Fungi,* Academic Press, Inc. London.

El-Amin, A.M., (2011) *Experimental Study on the Effectiveness of Natural Materials Used For the Protection of Mummies against Deterioration Caused By Insects with Application to an Ancient Mummy,* Cairo University, Faculty of Archaeology, Conservation Department, Thesis Submitted in Partial Fulfillments of the Requirements for the Degree of Master of Art in Conservation Sciences, Cairo, 39-43.

Elnaggar, A., Sahab, A., Ismail, S., Mahgoub, G., Abdelhady, M., (2010) Microbial Study of Egyptian Mummies: an Assessment of Enzyme Activity, Fungicides and Some Mummification Materials for the Inhibition of Microbial Deterioration, *e-conservation magazine*16, 39-49.

Espinoza, E.O., Baker, B.W., Moores, T.D., Voin, D., (2008) Forensic Identification of Elephant and Giraffe Hair Artifacts Using HATR FTIR Spectroscopy and Discriminant Analysis, Endang Species Res., Published online September 23, 2008, Inter-Research 2008, www.int-res.com

Estes, R.D., (1992) *The Behaviour Guide to African Mammals. Including Hoofed Mammals, Carnivores, Primates,* University of California Press, London, 63-115.

Fantner, G.E., Birkedal, H., Kindt, J.H., Hassenkam, T., Weaver, J.C., Cutroni, J.A., Bosma, B.L., Bawazer, L., Finch, M.M., Cidade, G.A.G., Morse, D.E., Stucky, G.D., Hansma, P.K., (2004) Influence of the degradation of the organic matrix on the microscopic fracture behavior of trabecular bone, *J. Bone* 35, 1013-1022.

Farlow, O., Argast, A., (2006) Preservation of Fossil Bone from the Pipe Creek Sinkhole (Late Neogene, Grant County, Indiana, U.S.A), *J. Paleont. Soc. Korea* 22/ 1, 51-75.

Farrell, E.F., Snow, C., Vinogradskaya, N., (2006) The Study and Treatment of Pa-Di-Mut's Cartonnage Mummy Case, *Journal of the American Institute for Conservation* 45/ 1, 1-15.

Gänsicke, S., Hatchfield, P., Hykin, A., Svoboda, M., Tsu, CM-A., (2003) The Ancient Egyptian Collection at the Museum of Fine Arts, Boston, Part 1, a Review of Treatments in the Field and Their Consequences, *Journal of the American Institute for Conservation* 42/ 2, Objects Issue, 167-192.

Hastorf, C.A., (1999) Recent Research in Paleoethnobotany, *Journal of Archaeological Research* 7/1, 55-103.

Hill, D.S., (1985) *Agricultural Insect Pests of Temperate Regions and Their Control,* London, 35.

Hrdy, D.B., (1978) Analysis of Hair Samples of Mummies from Semna South (Sudanese Nubia), *Am. J. Phys. Anthrop*. 49, 277-262.

Ikram, S., (2005) The Loved Ones: Egyptian Animal Mummies as Cultural and Environmental Indicators, *Proceedings of The Sixth International Symposium on The Archaeozoology of Southwestern Asia and Adjacent Areas,* Buitenhuis, H., Choyke, A.M., Martin, L., Bartosiewicz, L., Mashkour, M. (Eds), Arc-Publicaties 123 Groningen, Netherlands, 240.

Jadoul, A., Doucet, J., Durand, D., Preata, V., (1996) Modifications Induced on Stratum

Corneum Structure after in Vitro Iontophoresis: ATR-FTIR and X-ray Scattering Studies, *Journal of Controlled Release* 42, 165-173.

Johnson, J.S., (1994) Consolidation of Archaeological Bone: A Conservation Perspective, *Journal of Field Archaeology* 21/ 2, 221-233.

Joshi, M., Ali, SW., Purwar, R., (2009) Ecofriendly Antimicrobial Finishing of Textiles Using Bioactive Agents Based on Natural Products, *Indian Journal of Fibre & Textile Research* 34, 295-304.

Klys, M., Lech, T., Zieba-Palus, J., Biatka, J., (2001) A chemical and physiochemical investigations, *Mummy Result of Interdisciplinary Examination of the Egyptian Mummies of Aset-iri-khet-es from the Archaeological Museum in Cracow,* Cracow, 95-105.

Liao, W., Wei, F., Liu, D., Qian, M.X., Yuan, G., Zhao, X.Sh., (2006) FTIR-ATR Detection of Proteins and Small Molecules through DNA Conjugation, *Sensors and Actuators* B 114, 445-450.

Lombardi, G.P., (2001) Mummy Conservation and Paleopathology, *Chungará (Arica)* 33/1 Arica ene. versión On-line.

Lurker, M., (1984) *An Illustrated Dictionary of the Gods and Symbols of Ancient Egypt,* Thames and Hudson, London, 53, 54.

Maekawa, S., (1998) *Oxygen-Free Museum Case, Chapter 1 Conservation of the Royal Mummy Collection at the Egyptian Museum,* research in conservation, The Getty Conservation Institute, 3.

Meier, D., (2001) Mummies on Display: Conservation Considerations, Chungara: *Revista de Antropología Chilena* 33/1, 83-85.

Meneghini, C., Dalconi, M.C., Nuzzo, S., Mobilio, S., Wenk, R.H., (2003) Rietveld Refinement on X-Ray Diffraction Patterns of Bioapatite in Human Fetal Bones, *J. Biophysics* 84, 2021-2029.

Munro, J.W., (1966) *Pests of Stored Products,* London, 48.

Panagiotakopulu, E., (2001) New Records for Ancient Pests: Archaeoentomology in Egypt, *Journal of Archaeological Science* 28, 1235–1246.

Panayiotou, H., (2004) *Vibrational Spectroscopy of Keratin Fibres, School of physical and Chemical Science*, Queensland University of Technology in Partial Fulfilment of the Requirement of the Degree of PhD., 123.

Pouliot, R., Germain, L., Auger, F.A., Tremblay, N., Juhasz, J., (1999) Physical Characterization of the Stratum Corneum of an In Vitro Human Skin Equivalent Produced by Tissue Engineering and Its Comparison with Normal Human Skin by ATR-FTIR Spectroscopy and Thermal Analysis (DSC), *Biochimica et Biophysica Acta* 1439, 341-352.

Raper, K.B., Fennel, D.L., (1965) The genus Aspergillus, Williams and Wilkins, Baltinare, U.S.A.

Reiche, I., Favre-quattropani, L., Vignaud, C., Bocherens, H., Charlet, L., Menu, M., (2003) A multi-analytical study of bone diagenesis: the Neolithic Site of Bercy (Paris, France), *J. Measurement Science and Technology* 14, 1608-1619.

Robles, J., (2002) Blue bone analysis as a contribution to the study of bone taphonomy in San Josecito Cave, Nuevoleon, Mexico, *J. Cave and Karst Studies* 64, 145-149.

Robotham, C., FT-IR Microspectroscopy in Forensic and Crime Lab Analysis, www.thermo.com.

Rowe, W.F., (2010) Forensic Hair and Fiber Examinations in Archaeology: Analysis of Materials from Gravesites at the Home of Samuel Washington, *Technical Briefs In historical archaeology* 5, 43–51.

Russeau, W., Mitchell, J., Tetteh, J., Lane, M.E., Hadgraft, J., (2009) Investigation of the Permeation of Model Formulations and a Commercial Ibuprofen Formulation in Carbosil® and Human Skin Using ATR-FTIR and Multivariate Spectral Analysis, *International Journal of Pharmaceutics* 374, 17–25.

Schaffer E., (1971) Consolidation of Softwood Artifacts, *Studies in Conservation* 16/ 3, 110-113.

Stevens, R.B., (1981) *Mycology guide book committee,* Mycology Society of American University of Washington Press, Seattle, U.S.A.

Strandberg, Å., (2009) *The Gazelle in Ancient Egyptian Art. Image and Meaning.* Uppsala.

Te Velde, H., (1980) A Few Remarks upon the Religious Significance of Animals in Ancient Egypt, *Numen* 27, Fasc. 1, 76-82.

Titlbachova, S., Titlbach, Z., (1977) Hair of Egyptian mummies, In Multidisciplinary Research on Egyptian Mummies, *Zeitschrift fur Agyptische Sprache und Altertumskunde* 104, Strouhal, C.E. (Ed.), 79-85.

Tripathi, A.K., Upadhyay, Sh., Bhuiyan, M., Bhattacharya, P.R., (2009) A Review on Prospects of Essential Oils as Biopesticide in Insect-Pest Management, *Journal of Pharmacognosy and Phytotherapy* 1/5, 52-63.

Valentin, N., (2003) Microbial Contamination and Insect Infestation in Organic Materials, *Coalition* 6/1, 2-5.

Valentin, N., (1996) Assessment of Biodeterioration Process in Organic Materials, Control method, *International Conference in Conservation and Restoration in Archive and Library Materials,* 22nd -29th Vol. 1, Rome, 195.

Valentin, N., (2001) Microbial Contamination and Insect Infestation in Spanish Museums, Archives and Libraries, *Coalition* 3, 5-7.

Valentin, N., (2002) Non- Toxic Methods and Systems to Control Biodetreioration in Historic Object of Large Size, Cultural Heritage Research: A Pan-European Challenge, *Proceedings of the 5th EC Conference, May 16-18,* Cracow, Poland, 52-56.

Valentin, N., (2010) Microorganisms in Museum Collections, *Coalition* 19, 2-5.

Velkova, V., Lafleur, M., (2002) Influence of the Lipid Composition on the Organization of Skin Lipid Model Mixtures: An Infrared Spectroscopy Investigation, *Chemistry and Physics of Lipids* 117, 63–74.

Wei, Q.F., Wang, X.Q., Mather, R.R., Fotheringham, A.F., (2004) New Approaches to Characterisation of Textile Materials Using Environmental Scanning Electron Microscope, *Fibres & Textiles in Eastern Europe* 12/ 2 (46), 79-83.

Wilson, A.S., Dodson, H.I., Janaway, R.C., Pollard, A.M., Tobin, D.J., (2007) Selective Biodegradation in Hair Shafts Derived from Archaeological, Forensic and Experimental Context, *British Journal of Dermatology* 157, 450–457.

Wilson, S., Dixon, R.A., Edwards, H.G.M., Farwell, D.W., Janaway, R.C., Pollard, A.M., Tobin, D.J., (2001) Towards an Understanding of the Interaction of Hair with the Depositional Environment, *Chungará (Arica)* 33/2 Arica jul.

Xie, J., Riley, Cl., Kumar, M., Chittur, Kr. (2002) FTIR/ATR Study of Protein Adsorption and Brushite, Transformation to Hydroxyapatit, *Biomaterials* 23, 3609–3616.

Žemaitytė, R., Jonaitienė, V., Milašius, R., Stanys, S., Ulozaitė, R., (2006, Analysis and Identification of Fibre Constitution of Archaeological Textile, *Materials Science (Medžiagotyra)* 12/ 3, 258-261.

Zankiewicz, K., Kozajda, A., Piotrowska, M., S-Stańczyk, I., (2008) Microbiological Contamination with Moulds in Work Environment in Libraries and Archive Storage Facilities, *Ann Agric. Environ. Med.* 15, 71–78.