Mummy mania

Mummified remains from Egypt and beyond hold chemical information about the daily lives of ancient civilisations. Emma Davies reports

In short

- **Mummified remains in Egypt and elsewhere have fascinated archaeologists and chemists for centuries**
- **Chemical analysis can reveal the origins of some embalming ingredients**
- **Antibacterial and antifungal terpenoids and phenols in pine resins and pitches helped protect and preserve mummies**
- **Chemical evidence suggests ingredients were imported, giving insight into early trade**

Egyptian mummies have been prodded, poked, and pondered over by generations of archaeologists, scientists, and historians. The Victorians had a nasty habit of unwrapping and dissecting them, and mummies are now routinely scanned by medics hunting for cause of death and analysed by chemists eager to find out more about embalming chemicals.

The ancient Egyptians desperately wanted to be spoken of after their death, says Stephen Buckley, mummy expert and chemist at the University of York, UK. 'In a sense, chemistry is bringing them back to life.'

The ancient Egyptians used materials that were very much part of daily life for mummification. By revealing the tricks of the embalmer's trade, chemistry is uncovering the everyday lives of the Egyptians. Significantly, chemical analysis of mummies shows how embalmers used a host of highly effective antimicrobial and antifungal materials to preserve the bodies and provide safe transport to the afterlife.

Mummy methods

Research to date shows that Egyptian mummification was carried out in the Old Kingdom (2649–2152BC) and through the Late period (712–332BC), declining during the late Ptolemaic (c.200–30BC) and Roman (30BC–c.AD400) periods and stopping altogether when Islam was introduced in the seventh century AD.

The mummification process involved stripping the body of its internal organs – except the heart – and drying it using natron, a naturally occurring salt containing sodium carbonate, sodium bicarbonate, sodium chloride and sodium sulfate. Generally speaking, the dried body would have been stuffed with linen cloth and bags of various substances, including natron, resin-soaked bandages and sawdust. It would then have been coated with viscous, water-repellent materials to seal and protect it, and wrapped. In later periods, some embalmers sealed the eyes, ears, nose and abdominal incision with beeswax or bitumen.

Tomb paintings indicate the rituals and exotic ingredients used in Egyptian mummification

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The mummification balms were generally based on relatively cheap, readily available animal fat and plant oils, with more expensive – often imported – perfumes, wood oils, spices and resins or pitches added for their special symbolic and preserving properties. The plant and animal oils are not only hydrophobic but would have polymerised to produce a network capable of protecting fragile tissues and wrappings from microbial attack. Meanwhile, modern chemical analysis tells us that the the protective wood pitches, resins and oils would have contained disinfectant phenolic compounds, and molecules good at inhibiting microbial and fungal growth called terpenes.

Terpenes and related terpenoids are a family of molecules based on isoprene (2-methyl-1,3-butadiene). They are mainly made by plants and are classified by the number of isoprene units they contain. 10-carbon monoterpenes and monoterpenoids are made up of two isoprene units, 15-carbon sesquiterpenes three units, and 20-carbon diterpenes four units.

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The wide choice of materials available to Egyptian embalmers gives today's archaeological chemists a tough task in their chemical hunt. 'You have to look at just about everything,' says Buckley.

The best way to do this is to use gas chromatography–mass spectrometry (GC–MS) to look for biomarkers – stable molecules either present in original materials or, more usually, formed through ageing processes. 'Looking for biomarkers is tough, but some do survive and relate to the chemistry of the original compounds,' says Buckley. Over the years, researchers have built up a large database of biomarkers, many of which come from analysing materials that have been artificially aged under strictly controlled lab conditions. At London's British Museum, scientists routinely age materials and scour for biomarkers but also work on naturally aged plant materials, such as those held in 19th century collections in Kew Gardens, London, says Rebecca Stacey, a chemist at the museum.

Resins from coniferous trees such as pine, cedar, or fir hold a particular appeal for mummy scientists. Conifers are not indigenous to Egypt and their resins were probably imported from the eastern Mediterranean or the ancient Near East, which corresponds roughly to today's Middle East. Nevertheless they were widely used by embalmers from the Old Kingdom onwards and their general biomarkers are often relatively easy to spot. Their diterpenoid 'resin acids' make excellent biomarkers. For example, the conifer biomarker dehydroabietic acid can survive for millennia and is frequently found in mummy samples.

But narrowing down to conifer species using these mono- and sesquiterpene biomarkers is no mean feat. Unfortunately the compounds are volatile and readily change with age. 'In many cases you can only conclude that you have, say, a conifer resin, not which kind of pine or whether you have pine or cedar,' says Francesca Modugno, a member of the Chemical science for the safeguard of cultural heritage group at the University of Pisa, Italy, led by Maria Perla Colombini.

But that's not to say that the Pisa team isn't working on ways to extract the species information. A reliable way to spot a conifer species in mummy resins would release valuable information on ancient trade routes. Jeannette Jacqueline Łucejko has been recreating pitch formation in the lab using pine and cedar samples collected from Pisa's botanical garden. She heats woods at 500°C in the absence of oxygen and compares the resulting mixtures with those found in mummies.

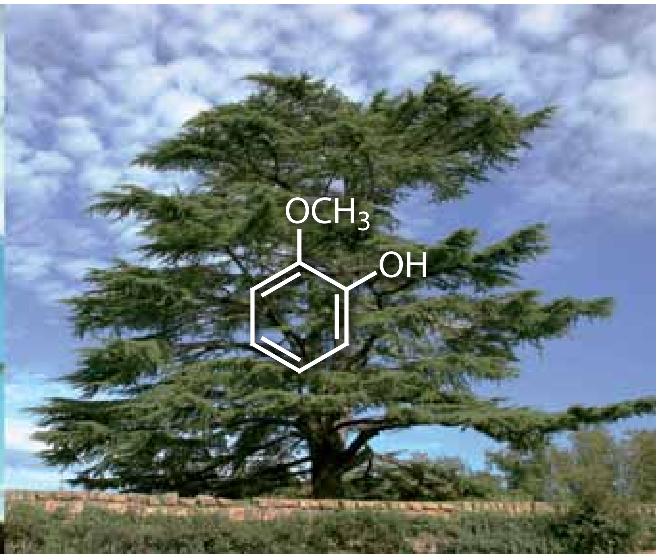
Identifying materials used in embalming can give insight into trade routes and daily life

'Looking for biomarkers is tough, but some do survive and relate to the original embalming compounds'

The Pisa team used GC-MS to analyse Egyptian embalming materials held at the Natural History Museum of the University of Florence, Italy, and compared the results with the modern pitch data. Polycyclic terpenes and acidic diterpenes led them to conclude that the mummy balms consisted mainly of 'pine pitch'. They also found sesquiterpenoids and phenols which are highly likely to have come from cedar oil but remain cautious in their analysis because of the compounds' volatile nature.[1]

Smoke signals

Many sources suggest that cedar pitches were used for mummification and ancient texts by the Roman scholar Pliny and Greek historian Herodotus link a wood called 'cedrium' to embalming. Ursula Baumer at the Doerner Institute in Munich, Germany, is certain that her team found cedar materials in unused ancient Egyptian embalming materials from Deir el-Bahari, an Egyptian complex of mortuary temples and tombs dating from about 1500BC. GC-MS analysis



Terpenoid biomarkers like dehydroabietic acid from conifer trees and phenols like guaiacol from cedar oil can give clues to embalming ingredients

revealed the presence of phenols and sesquiterpenoids and, importantly, a compound found in wood smoke called guaiacol.

Baumer and her team attributed the guaiacol to a tar oil produced from cedar wood, known to be rich in the compound. The embalming material would have had 'powerful bactericidal and fungicidal activity,' the researchers say.

To show just how effective cedar would have been for embalming, Baumer and her team measured levels of the enzyme alkaline phosphatase, which binds tightly to hydroxyapatite in bones and can apparently survive for thousands of years, provided there is no microbial attack. Baumer's team coated pigs' ribs in guaiacol and measured alkaline phosphatase levels, which turned out to be seven times higher than in untreated bones. The guaiacol had apparently had a 'sealing effect', trapping high levels of alkaline phosphatase in the bone. Guaiacol and its derivatives would also have cross-linked with keratin, the structural protein in skin, to give a rigid structure. Such cross-linking would have been great for the embalmers but not so good for today's archaeological chemists, hiding the guaiacol from chemical detection.

Bit of bitumen

York's Buckley did his PhD on Egyptian mummies with Richard Evershed at the University of Bristol, UK. This team was one of the first to study dated Egyptian mummies with authenticated provenance (from 1900BC to AD395) using modern chemical techniques, a little over a decade ago.

One of the substances they looked for was beeswax, introduced long after conifer resins, and characterised by alkanes, wax esters and hydroxy wax esters. The black resinous coating of one Ptolemaic mummy the team analysed turned out to be 87 per cent beeswax, mixed with a small amount of resin from trees in the pistachio (pistacia) family.

Buckley and Evershed's research[2] suggested that ancient Egyptian embalmers used a far wider variety of materials than had previously been thought. At one time, bitumen was considered to have been the main embalming ingredient, largely because of the amorphous black appearance of many mummies. 'Their appearance brings to mind bitumen but it is not necessarily the case,' says Stacey. 'Sometimes

Not all mummies are Egyptian. There are mummified remains all over the world, including in Peru and Yemen

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the discolouration is because of oxidation and ageing and sometimes it is conifer pitch and resin.'

Buckley had the opportunity to analyse a shiny, black 'Early Kingdom' mummy in Bristol Museum, which was labelled as being coated in bitumen. When he took the sample back to the lab he was surprised to discover that the predominant ingredient was paraffin wax. Rifling through museum records revealed that museum staff had indeed coated the mummy in paraffin wax. 'The mummy had been in a light box for decades and had turned completely black and very shiny with oxidation,' recalls Buckley.

Stacey had a similar experience at the British Museum when analysing samples from the 'Granville mummy', famously unwrapped and dissected by Augustus Granville during the peak of mummy mania in 1821. Granville had deduced that 'the body must have been plunged into a vessel containing a liquefied mixture of wax and bitumen and kept there for some hours or days, over a gentle fire.'

Stacey was able to throw out this theory using GC-MS, finding no evidence for beeswax or bitumen but instead finding degradation products from conifer resin acids. Indeed, pimaric acid had survived from the original resin. But bitumen was commonly used in later mummification and Buckley and Evershed even found it in Pharaonic mummies of pets, embalmed as painstakingly as humans.

Colombini's Pisa team worked on 'Merneith's mummy' from the seventh century BC, finding pistacia resin, vegetable oil, beeswax and bitumen. They identified terpenoids that had clearly come from a thermal treatment, backing the theory that a hot fluid was used for embalming in the Late period. Heating the mixture allowed it to be poured into the body, giving brown degraded compounds which would have given the mummy her black appearance when combined with bitumen.

Meanwhile, Natalie McCreesh from the University of Manchester's KNH Centre for Biomedical Egyptology has used a technique called micro-scale sealed vessel GC-MS to detect bitumen in ancient Egyptian samples from Manchester Museum and the British Museum. The pyrolysis thermally breaks down samples, requiring no wet chemistry and less than 1mg of sample. All of the samples that she analysed, from the Third intermediate period to the Late period, contained bitumen. She also found evidence for 'ancient hair styling products', suggesting that the hair was treated separately to the rest of the body to maintain the deceased's hair style. In work with York-based Egyptologist and ancient hair expert Joann Fletcher, Buckley has seen something similar in a mummy dating from around 500BC, where elaborately curled hair had been fixed in place with beeswax, absent from the embalming recipe.

Black coatings on a mummy might be bitumen used in embalming, but could just be oxidised paraffin wax applied by museum staff

Museum trip

Most of the European work on mummies has to be done on museum exhibits since Egypt has banned removal of samples from the country in all but exceptional circumstances. Working on exhibits brings a whole set of chemical challenges. Not only do researchers have to consider the original archaeological environment but they also have to factor in museum handling and storage conditions. 'It's very challenging material but that's part of the attraction,' says Stacey.

And there is still much research to be done on museum samples, such as analysis of carbon isotope ratios, says Pisa's Modugno. 'There is a also a lot of work to be done to understand which products were used in non-Mediterranean areas,' he adds.

Buckley has already started projects far from Egypt. As part of a York team, he has worked on mummies from Peru, claiming to have found the first conclusive scientific evidence of embalming practices there in 2007. 'What they were doing was actually quite a complicated procedure,' he says.

As with ancient Egypt, Buckley thinks that much of the Peruvian embalming process was symbolic. For instance he identified insect wax on the limbs of one South American mummy dated to AD1100 whose head was coated with a plant wax. 'In South American mythology, many-limbed creatures are part of the world of deities, including human-headed scorpions and spiders,' says Buckley.

Buckley's work on South American mummies also hints at wider trade links with the rest of the world than previously thought. He hopes to publish the results this year but until then remains tight-lipped.

Buckley has also worked on mummy materials from Yemen from around 700 to 400BC. Getting access to the mummies proved difficult to say the least, with local tribal disputes and challenging topography. 'It was a very interesting experience,' he says. Until recently, Yemeni mummies were thought to have been extremely basic. Proposed preservatives include the hygroscopic plant el-Raa, which could have been used as a desiccant. Buckley and the rest of the York and Yemeni team used GC-MS to study samples from four Yemeni mummies and found animal fat, most likely from a camel, plant wax, a gum or sugar and aromatic acids hinting at a plant extract, possibly a resin similar to the highly perfumed storax extracted from the bark of Styrax trees. Buckley is confident that a 'complex recipe' was used to embalm the Yemeni mummies. 'What is really quite interesting to me is that the materials they were using were chosen to identify them with Sheba,' he says. The location of the famous kingdom of Sheba is disputed, but many scholars suggest it was in Yemen.

Beeswax was a common embalming ingredient, and could even be used to fix a mummy's hairstyle

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Pure chemistry

Buckley sometimes gets frustrated with what he sees as the snobbery of some chemists 'who think that doing chemistry and archaeology is a bit frivolous'. 'Not only is it justified in itself but by having unusual mixtures put together and then processed you're actually finding molecules that are quite rare, telling us something interesting about chemistry in its purest sense,' he counters.

Emma Davies is a freelance science writer based in Bishop's Stortford, UK

References

1 This research is not yet published and the researchers would like to thank J Moggi, M Zavattaro and S Boccone from the Natural History Museum, University of Florence, Italy, for providing archaeological samples

2 S A Buckley and R P Evershed, *Nature*, 2001, **413**, 837