Research with Egyptian Mummies
A bioarchaeological approach to the past

by

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Content

Declaration of authorship

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Peer review

All papers presented for this PhD have been already peer-reviewed and approved by the editors of the journals according to their publication standards and the standards of the discipline wherein they are published.

Definition of the material used

The thesis focuses on bioarchaeological material, mostly from dynastic Ancient Egypt (ca. 3000 – 30 BC) with one exception (the mummy with stroke) and is limited to human remains.

Declaration of Ethics

Ethical clearance was either not needed or is declared in every published paper following the legal requirement of the respective country and museum (or owner).
In any case, the code of ethics by the Institute of Evolutionary Medicine was applied in addition (http://www.iem.uzh.ch/en/institute/iemcodeofethics.html)

Acknowledgment

Many people have collaborated and supported my research in the last years. In the first place my mother Elisabeth Habicht, who always supported me in all the years.

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Introduction

In the public perception of Ancient Egypt, most people think of pyramids, hieroglyphs and mummies. This tradition goes back even to ancient times as foreign visitors made remarks on the strange funerary customs in Egypt (Germer 1994, 11): Herodotus (490/80 – 430/20 BC) made detailed remarks on mummies in his second book (Macaulay 1890; Felix 1965), as well as Diodorus of Sicily (first half of the 1st cent BC) (Diodorus, I, 91). The tradition of Egyptian mummification is also mentioned in the Bible (Moses I, 50), reporting the treatment of the body of Jacob, father of Joseph who died in Egypt and was embalmed in Egyptian way according to the wish of Joseph.

Even in the modern world mummies retain a special, and occasional morbid, fascination.

Almost from the very beginning of movie industry they have been included in horror movie (Frayling, Davies, and Towers 1992; Frayling 1996) and they inspired various writers using them as part of stories, e.g. Bram Stoker "The Jewel of the Seven Stars" (Stoker 1903) or Arthur Conan Doyle's "Lot No. 249" (Conan Doyle 1922).

During the Middle Ages and the early modern age, mummies were also used as "medicine" or a remedy for almost every disease. The ingestion of dead bodies is quite a morbid and questionable tradition and as widely practiced from the 13th onwards. By the 18th century an Egyptian mummy was almost a "must have item" for any respectable pharmacy (Germer 1994, 17). It was during the 19th century, when true medicine was taking over the field that the use of "Mumia vera" disappeared. The latest record of sale is a price list from the German company E. Merck in Darmstadt from 1924, selling "Mumia vera Aegyptiaca" with the impressive price of 12 Goldmark per kilogram (today gold value c. 226 Australian Dollar) (Germer 1994, 18).

The mummy as an object of scientific study

Mummies are of greatest interest for scientific research and Ancient Egypt has a very special place in this field of bioarchaeology, as they can provide deeper inside in medical conditions due to the preservation of soft tissue. (Buikstra 1977; Larsen 1987; Larsen 1997). Mummies are reported worldwide and from many time periods, but they are only a sample from the population: Natural mummies are often preserved randomly and often we have only a small and unrepresentative sample from a civilisation and little information on the deceased individual.

In the case of artificial mummification, we are often faced with the fact that only the elite are represented (popes and incorruptible saints of the Roman Catholic Church, emperors and kings). Some of these mummies are of the highest interest for history and the evolution of disease, e.g. the famous ice man (Ötzi), naturally mummified but exceptionally well (Seiler et al. 2013) or the remains of the Medici in Florence (Fornaciari 1999; Fornaciari and Gaeta 2013; Fornaciari et al. 2018) as well as the Aragonese Kings of Naples (Gaeta, Giuffra, and Fornaciari 2013).

Only in Ancient Egypt do we have an abundance of mummies, covering broader parts of the general population from the middle class upwards to the divine pharaohs of Egypt. This unique fact offers the possibility to learn about the living conditions and health of the people and combine these insights with archaeological and written evidence.

Egyptian mummies also have been the subject of scientific research for many centuries. One of the earliest treatises was posthumously published by P. Camerarius (1537 – 1624) (Camerarius and Maier 1625) and Thomas Pettigrew in 1834 (Pettigrew 1834). One of the first scientific mummy autopsies was performed on the bodies of the "two brothers" in Manchester in 1908 by Margaret Alice Murray (1863 – 1963) (Murray 1910).

Shortly after the discovery of x-rays by Conrad Roentgen the new technology was applied by C. Koening (1859 – 1936) who performed the first x-ray of mummified tissue in 1896 (Koenig 1896). Most investigations at this time were conventional autopsies which involved opening of the wrappings and sometimes the thorax or abdomen. Such drastic invasive investigation gave much insight into the art of embalming and revealed the faces of the pharaohs to the public (Smith 1912; Partridge 1994; Bickerstaffe 2009). The opening of the mummy bundles often caused problems, as they started to decay after being exposed to fresh air.

A systematic investigation of the mummies started after the discovery of the first Royal cachette in Deir el-Bahari (tomb DB 320) in 1881, holding almost half of all known kings of the New Kingdom (Brugsch and Maspero 1881). In 1898 the second cachette in tomb KV 35 was discovered by French archaeologist Victor Loret (Piacentini and Orsenigo 2004). Now Egyptology was in possession of most of the kings and few queens of the New Kingdom. These lucky discoveries lead to a first almost complete investigation of the Royal remains by Grafton Elliot Smith published in 1912 (Smith 1912).

In the following decades mostly single case studies were undertaken, often performed by Douglas E. Derry, deepening the understanding of Ancient Egyptian mummification (Derry 1939; Derry 1940; Derry 1942).

The discovery of a mummy in the cachette KV 55 in the Valley of the Kings produced the greatest enigma in the investigation of the royal mummies (Davis 1910). It was reduced to a skeleton shortly after discovery and not only has been changed sex after the anthropological examination (from female to male – from Queen Tyje to King Akhenaton). Its identification also has been changed several times from one historical personality to another. He is either regarded as King Akhenaton (Smith 1912; Hawass et al. 2010; Habicht 2011; Gabolde 2013) or as enigmatic Pharaoh Smenkhkare (Derry 1931; Harrison 1966; Duhig 2010). While this still ongoing debate is mostly fought in expert circles, the public focus is always on his close relative, King Tutankhamun: Culmination of public interest in mummy research was the first autopsy on the newly discovered mummy of Tutankhamun, investigated by Howard Carter and Douglas E. Derry in 1925 (Derry 1927). The results achieved were rather disappointing: Derry could determine the age and reported a close relationship to the mummy found in KV 55 but no further information could be determined. The cause of death remained mysterious. Later

investigations could add little to the knowledge (Harrison and Abdalla 1972; Leek 1972). Despite – or because of – the lack of hard evidence, the theories were abundant as a recent review demonstrated (Rühli and Ikram 2014). Today, only two explanations are considered to be realistic causes of death: Tutankhamun either died as a result of a knee injury (Hawass et al. 2007) or perhaps of malaria (Hawass et al. 2010).

In the field of general population research, several catalogues of great museums pushed the benchmark upwards (Dawson and Gray 1968; Delorenzi and Grilletto 1989; Raven and Taconis 2005). The mummy investigation implemented as general method the x-ray and later CT-scan as non-destructive methods. Outstanding in applying multiple approach methods to penetrate deeply into the secrets of the dead is the Manchester Mummy Project by Rosalind David (David 1979). Not only facial reconstruction but also unusual methods as fingerprinting by the British police were attempted.

Genetics

Genetic investigation of Egyptian mummies is highly challenging and was attempted first by Pääbo in 1985 (Pääbo 1985), but later the results turned out to be modern contamination. The study of Malmström revealed the great problem of modern contamination by testing animal mummies for traces of human genomes (Malmström et al. 2005).

The Egyptian Supreme Antiquity Council (SCA) started the "Tutankhamun Family Project" to investigate and identify the ancestry of Tutankhamun. Some members of the family are identified (Juya and Thuya, the grandparents on the maternal side), while other mummies were suspected candidates for a close relation.

The results were presented in February 2010 and caused significant media interest, most resulting from the celebrity status of Tutankhamun and less from the actual results, as they mostly seem to confirm previous suspicions (Hawass et al. 2010). One of my publications addresses these investigations from the time of the discovery until 2016 (Habicht, Bouwman, and Rühli 2016).

The identification of Tutankhamun's parents is still controversial as is the entire genetic data base (Lorenzen and Willerslev 2010; Timmann and Meyer 2010; Gad 2010). So far, only one of the most recent studies by Verena Schuenemann and Johannes Krause is generally accepted (Schuenemann et al. 2017).

Nefertiti as an example for the controversy of Identification

The fact that unidentified mummies in collections can yield a sensational identification is pivotal for one of the papers presented in this thesis (Habicht et al. 2016). The topic can be illustrated by investigating the ongoing search for Queen Nefertiti, the famous wife of Pharaoh Akhenaton. In 2015, British archaeologist Nicholas Reeves claimed that behind the northern wall of Tutankhamun's burial chamber might be an additional structure (corridors and chambers?) and that they potentially contained the undisturbed burial of Nefertiti (El-Aref 2015; Reeves 2015). While his observation on the alteration

of the art canon and the fact that the background of the wall was changed from white to yellow-ochre is undisputable, many experts questioned the suspected burial of Nefertiti (Müller-Römer 2015; Lorenzi 2015; Habicht, Galassi, et al. 2015; Arrizabalaga 2015). The mummy of the so-called "Younger Lady" from KV 35 has been known to science since 1898. For a long time, she was considered to be an unnamed relative of Pharaoh Amenhotep II (mostly because tomb KV 35 was originally the tomb of Amenhotep II – but later used as depot for many royal mummies from various dynasties).

By end of the 20th century, British Egyptologist Joann Fletcher suggested that this unidentified mummy might be the famous Queen Nefertiti, based on various and very convincing arguments (Fletcher 2004; Wortman 2003). A forensic facial reconstruction on the skull showed a close resemblance to the famous bust of Nefertiti in Berlin and other busts and statues (Habicht 2011, colour plate IV).

When the genetic results were published in 2010, the "Younger Lady" was identified as the genetic mother of Tutankhamun, but the authors of the study did not identify her as Nefertiti. Historical inscriptions strongly suggested, that Nefertiti might have been the mother of Tutankhamun (Gabolde 1998; Habicht 2011, 154; Schlögl 2012, 87, Fig. 23). My publication from 2011 was actually the starting point of entering the field of mummy research, supporting the identification of Fletcher that the "Younger Lady" is indeed Queen Nefertiti (Habicht 2011). Highly controversial in the beginning, more and more experts have followed this identification, e.g. Hermann. A. Schlögl (2012) and Marc Gabolde (2013).

A new facial reconstruction of the "Younger Lady" based on a 3D scan of the mummy (not on the skull) and more advanced facial reconstruction was revealed to the public in February 2018 (Thews 2018; Balaji 2018; Gates 2018). Modelled on the 3D print, the team from Bristol (Aidan Dodson and Élisabeth Daynès) created a flesh-like bust with silicon and glass eyes. The identification of the "Younger Lady" as Nefertiti is now practically 99% certain. This development shows the importance of positive identification and the use of modern forensic technologies. Such methods are also applied in my papers presented for the PhD.

The Swiss Mummy Project

The project was founded by Frank Rühli and Thomas Böni in 1995 with the aim to investigate all the Egyptian mummies in Swiss collections and was later enlarged to study mummies worldwide. Still today, the exact number of mummies in collections, libraries and private collections is not known, as a global database does not yet exist.

It is an honour to be a part of this team since 2012, conducting several mummy studies and contributing to the deeper understanding of the Ancient Egyptian culture in this very special aspect of bioarcheology.

Abstract

The thesis for a PhD by publication presents a number of different methodological approaches to mummy research. Several papers produced results related to various aspects of past life in Ancient Egypt. Most of these studies suffer from the same problems that have limited previous research involving ancient mummies: Either the mummies are still wrapped and could therefore not be sampled using invasive methods (e.g. in case of Kha and Merit) – or only parts of the body are preserved, limiting the possible applications and questions (e.g. Nefertari). Alternatively, the soft tissue is entirely decayed, leaving only the bones. In such cases, any disease affecting soft tissue or the skin and hair escapes our abilities of detection (e.g. Meresankh III).

Part 2 illustrates the possibilities and limitations of mummy research (explained in detail in the contribution). Most investigations have to be custom designed, as every individual case has its distinct particularities and limitations. Non-invasive investigations are normally possible and yield little risk, while sampling is not always possible or useful. Most challenging was the genetics, yielding practically no conclusive results, as related ancestry or kin are unknown or not yet investigated. For the time being, there is no strategy against this fact, only larger series of genetic profiles may reveal unknown family relationships.

The last part of the thesis highlights the importance of accurate dating and chronology for mummies in relation to the exclusion of false assumptions. The dating is further complicated by the still ongoing discussion of the chronological model itself (high or low).

List of selected publications

The direct link connects the paper with the online repository of the publisher. In cases where the paper is behind a pay-wall but the embargo period for self-storage is expired, the alternative link can be used. The impact factors are based on the Thompson Reuters list and on the SJR tool used by Flinders University. Most of the papers can also be found on: http://unizh.academia.edu/MichaelEHabicht

Michael E. Habicht, Maciej Henneberg, Lena M. Öhrström, Kaspar Staub, Frank J. Rühli

Body height of mummified pharaohs supports historical suggestions of sibling marriages.
American Journal of Physical Anthropology (2015) 157(3): 519-525.
Impact Factor: 1.452 (SJR) / 2.824 (Thompson Reuters) (Habicht, Henneberg, et al. 2015)
Direct link: Body Height
Alternative link: Body Height

Michael E. Habicht, A.S. Bouwman, F.J. Rühli

Identifications of Ancient Egyptian Royal Mummies reconsidered.
American Journal of Physical Anthropology (2016) 159 (Suppl. 61): 216-231. doi: 10.1002/ajpa.22909.
Impact Factor: 1.452 (SJR) / 2.824 (Thompson Reuters) (Habicht, Bouwman, and Rühli 2016)
Direct link: Identification of Royal Mummies

Raffaella Bianucci, Michael E. Habicht, Stephen Buckley, Joann Fletcher, Roger Seiler, Lena M. Öhrström, Eleni Vassilika, Thomas Böni, Frank J. Rühli

Shedding New Light on the 18th Dynasty Mummies of the Royal Architect Kha and His Spouse Merit.
PLoS ONE (2015) 10 (7) e0131916. doi: 10.1371/journal.pone.0131916. eCollection 2015. Impact Factor: 1.201 (SJR) / 3.54 (Thompson-Reuters) (Bianucci et al. 2015) Open access paper.
Direct link: Kha and Merit

Michael E. Habicht, Raffaella Bianucci, Stephen Buckley, Joann Fletcher, Abigail S. Bowman, Lena M. Öhrström, Roger Seiler, Francesco M. Galassi, Irka Hajdas, Eleni Vassilika, Thomas Böni, Maciej Henneberg, Frank J. Rühli

Queen Nefertari, the Royal Spouse of Pharaoh Ramses II:
A Multidisciplinary Investigation of the Mummified Remains Found in Her Tomb (QV 66).
PLoS ONE (2016) 11(11): e0166571. doi: 10.1371/journal.pone.0166571.
Impact Factor: 1.201 (SJR) / 3.54 (Thompson-Reuters) (Habicht et al. 2016).
Direct link Nefertari
Preliminary results were presented at the International Conference of Egyptologists ICE XI in Florence (Italy) (Rühli et al. 2017).

Francesco M Galassi, Maciej Henneberg, Wouter de Herder, Frank Rühli, Michael E Habicht

Oldest case of gigantism? Assessment of the alleged remains of Sa-Nakht, king of ancient Egypt

The Lancet: Diabetes-Endocrinology (2017) 5: 580-581.

Impact Factor: 8.625 (SJR) / 19.7 (Thompson-Reuters) (Galassi, Henneberg, et al. 2017).

Direct link: Gigantism

Francesco M. Galassi, Michael E. Habicht, Frank J. Rühli, Stefano De Carolis

A Unique Case of Stroke and Upper Limb Paralysis in a Mid-18th Century Natural Mummy.

Circulation Research, 2017, Vol. 121 (4), 338-340.

Impact factor: 13.965 (Galassi, Habicht, et al. 2017).

Direct link: Case of Stroke

Francesco M. Galassi, Michael E. Habicht, Frank J. Rühli

Poliomyelitis in Ancient Egypt?

Neurological Sciences, 2016, Vol 38 (2), 375.

Impact Factor: 1.749 (Galassi, Habicht, and Rühli 2016).

Direct link: Poliomyelitis

Michael E. Habicht, Patrick E. Eppenberger, Francesco M. Galassi, Frank J. Rühli, Maciej Henneberg

Queen Meresankh III – The oldest Case of Silent Sinus Syndrome

Anthropology. International Journal of Human Diversity and Evolution (CZ), Vol. 56 (1) 2018. https://doi.org/10.26720/anthro.17.09.25.2 (Habicht et al. 2018).

Direct link: Meresankh III

Michael E. Habicht; Rita Gautschy; Renate Siegmann, Daniela Rutica; Rainer Hannig

A New Sothis Rise on a Small Cylindrical Jar from the Old Kingdom.

Göttinger Miszellen (2015) 247: 41-50.

Direct link: Sothis

Rita Gautschy and Michael E. Habicht, Francesco M. Galassi, Daniela Rutica, Frank J. Rühli, Rainer Hannig

A new astronomically based chronological model for the Egyptian Old Kingdom.

Journal of Egyptian History (2017) 10(2): 69-108.

Direct link: Chronology

Contribution

In five papers, I was the first author and in one case co-first author and therefore contributed to conception, investigation (mostly the Egyptological aspects) and writing the manuscript, submission and revision.

Part 1: Physical Anthropology of Ancient Egypt

Part 1 is concerned with the general physical anthropology of ancient Egyptians and their body proportions (especially the body height).

Michael E. Habicht, Maciej Henneberg, Lena M. Öhrström, Kaspar Staub, Frank J. Rühli

Body height of mummified pharaohs supports historical suggestions of sibling marriages.

American Journal of Physical Anthropology (2015) 157(3): 519-525 (Habicht, Henneberg, et al. 2015)
Direct link: Body Height
Alternative link: Body Height

Statement

The work is original in its overall conception of comparing a general population pool with the royal families ruling over Egypt. The data were taken from various sources and are fully referenced. The body height of the Predynastic to the Old Kingdom is based on previous data collection. The data for the New Kingdom to the Greco-Roman period did not exist as a coherent body of work and was mined by checking every available museum catalogue and countless single case studies. The calculations are entirely new.

The first author developed the concept and undertook all the data mining and the writing of the manuscript. In working with body height formulae, he was supported by Kaspar Staub and Maciej Henneberg. Lena M. Öhrström provided CT-scan pictures of mummies enabling the first author of measuring additional mummies. Revision of the manuscript following reviewers' comments was mostly made by the first author.

Introduction

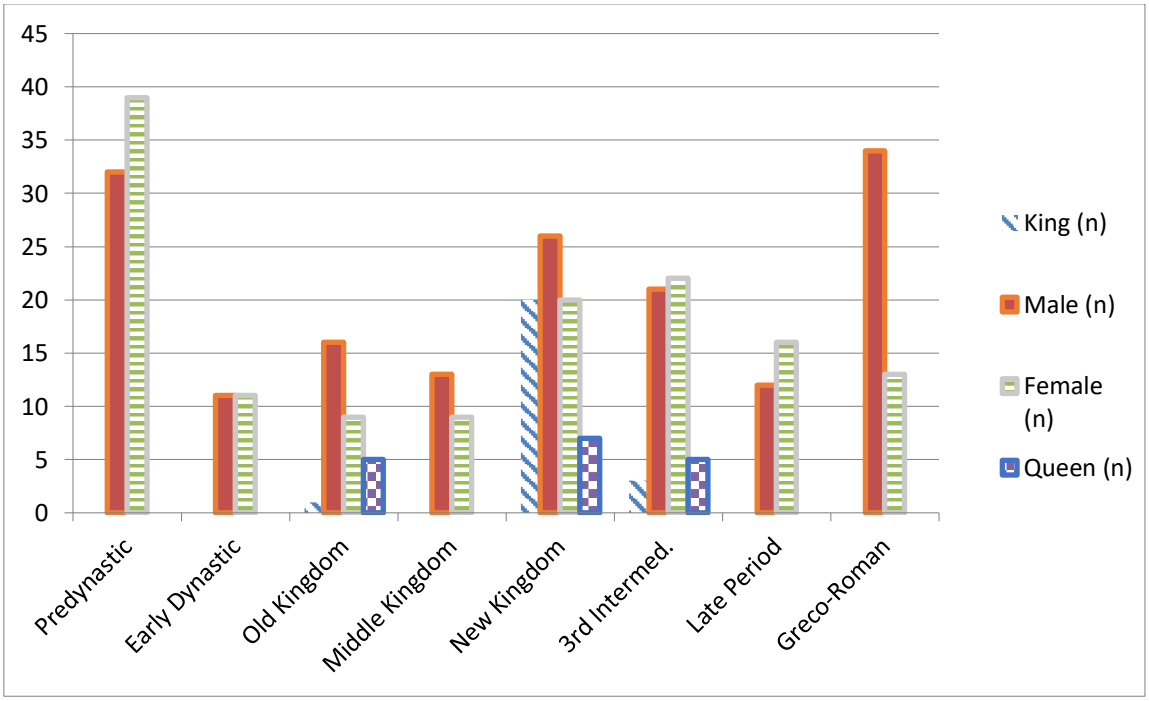
The study faced huge problems, as many publications involving mummies do not include proper body height measurements (often only an overall length is given), while osteometrically correct measurements of long bones are often absent. With the lack of any measurements, a great number of mummies could not be used at all. In addition, we removed all non-adult individuals to avoid statistical problems. Based on previous studies (Robins and Shute 1983 Robins and Shute 1986; Zakrzewski 2003) we collected

259 datasets of individuals for body height (116 females and 143 males) including all available data for the kings, queens, high priests of Amun and other members of the royal families. It is the largest study on body height in Ancient Egypt presented so far.

The study is still accurate in all conclusions. In the years after the publication, some additional information was added to our data collection. They do not significantly change the statistics and support the validity of the applied method: A collection of mummies in Czech and Slovak republics (former Czechoslovakia) was added (Strouhal and Vyhnánek 1980). Two other mummies mentioned in an older museum series from the University of Pennsylvania Museum were also added to the general pool (Fleming et al. 1980). The effect on the reconstructed average body height is insignificant because of the small sample size and regular body heights of the new individuals. In the pool of the royals, the mummy of King Neferefre (5th dynasty) was added (Strouhal and Vyhnánek 2000). His body height of about 168 cm was calculated using Martin & Saller measurement rules (Martin and Saller 1957). Four female members of the royal court of King Djedkare were also added (Strouhal 1984, 1992; Verner, Callender, and Strouhal 2002): Princess Khekeretnebty, Princess Tisethor, Princess Hedjetnebu and a female member of the elite (her name is lost, therefore she is called "Lady L" after her mastaba L).

- Khekeretnebty: 156 cm
- Tisethor: 151 cm
- Hedjetnebu: 152 cm
- Lady L: 157 cm

The female members of the royal family in the Old Kingdom are described as slender and gracile built and are (except Lady L) below average female height.



The new sample size for the collection is n=278 (male n=154; female n=124).

Male

1. Six new male mummies from the New Kingdom increase the sample size considerably, the male average body height in the New Kingdom drops minimal (from 162.8 to 162.6 cm.)
2. No changes or additions in the 3rd Intermediate Period (163.6 cm).
3. Male average height in Late Period drops from 165.5 cm to 164.7 cm, caused by an unusually short man of only 156 cm.
4. Male average height in Greco-Roman age remains at 164.4 cm.

Female

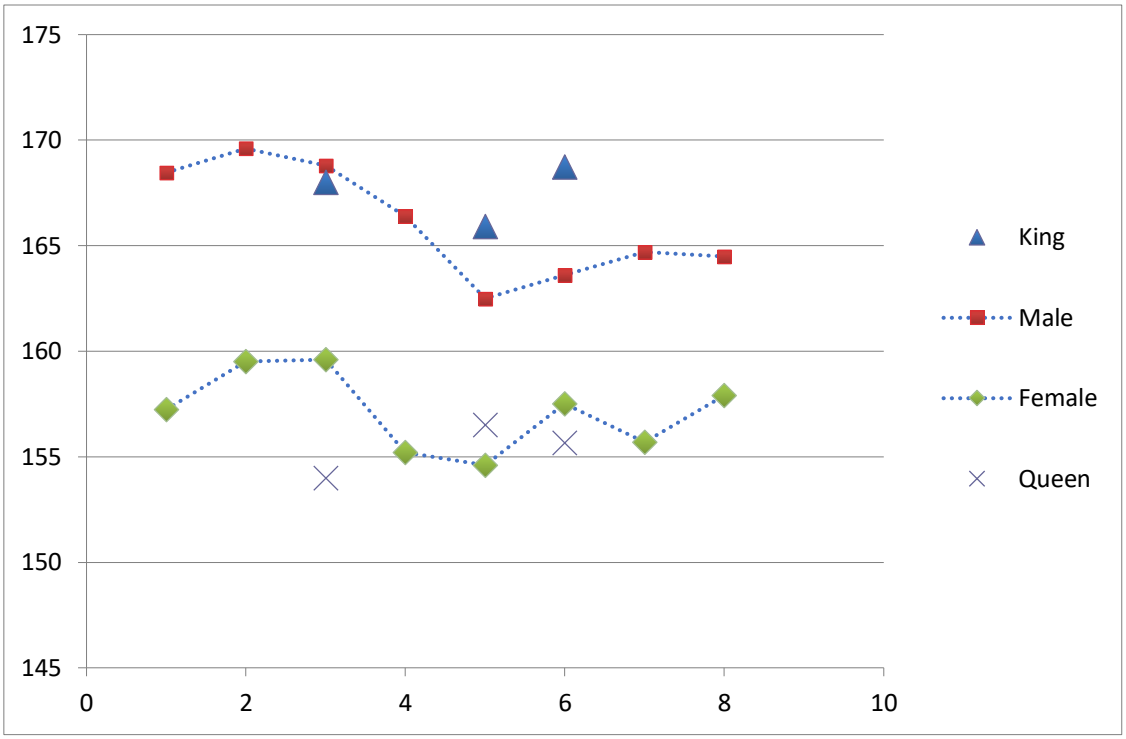
1. Two additional female mummies from the New Kingdom increase the very small sample size to n=5. The average female height rises from 156.3 to 157.4 cm.
2. Two new female mummies in the 3rd Intermediate Period lower the average body height from 158.1 down to 157.5 cm.
3. In the Late Period, two new mummies altered the average body height from 155.6 to 155.7 cm
4. Two additional female mummies in the Ptolemaic-Roman period changed the body height from 157.6 to 157.9 cm.

Kings

The sample size of n=1 in the Old Kingdom is too small to make any statement of draw any conclusion for a whole epoch, but King Neferefre is above average male height.

Queen and Princesses

The five known body heights of female royals (c. 154) from the Old Kingdom are below female body of their age (ca. 159.6 cm).



1 Predynastic

2 Early Dynastic

3 Old Kingdom

4 Middle Kingdom

5 New Kingdom

6 Third Intermediate Period

7 Late Period

8 Greco-Roman Period

Conclusion

The new data did not change the general trend or any result in a significant manner. The ‘male taller than women”-norm is not affected. The female royals of the Old Kingdom are representative for the ‘ideal queen’: smaller than the King and slender built.

Further research is ongoing. The body height of Queen Nefertari, favourite Queen of Ramses II is published (Habicht et al. 2016). Her body height was reconstructed as 165 cm (+/- 2.5 cm) using two different approaches leading to the same reconstruction. Queen Nefertari probably was considerably taller than the average women of her time; she had the size of average male. But the “man taller-norm” (Pierce 1996) is still effective, since she was married to one of the tallest Pharaohs (Ramses II was c. 173 to 175 cm tall).

The newly discovered King Senebkay User-ib-Ra was first reported to be 185 cm (Wegner 2014a; Loges 2014; Wegner 2014b). Later the body height estimation is lowered to 180-183 cm. The King probably

died of massive head trauma, perhaps caused by weapons, similar to those used against King Seqenenre Taa (ten Berge and van de Goot 2002; Bietak and Strouhal 1974; Bockenheimer et al. 1978).

An Austrian research team reported in their conference presentation ‘Arsinoe IV of Egypt, sister of Cleopatra identified? Osseous and molecular challenges.’ that Arsinoe IV, half-sister of Cleopatra VII had a body height of c. 154 cm (Trotter and Gleser formula for a femur was used) and was very gracile. With an estimated age of c. 15 years she was not yet fully grown (Kanz, Grossschmidt, and Cemper-Kiesslich 2009).

Michael E. Habicht, A.S. Bouwman, F.J. Rühli

Identifications of Ancient Egyptian Royal Mummies reconsidered.

American Journal of Physical Anthropology (2016) 159 (Suppl. 61): 216-231

doi: 10.1002/ajpa.22909. (Habicht, Bouwman, and Rühli 2016)

Direct link: Identification of Royal Mummies

Statement

Original parts of the work: The first author developed the concept of the study, analysed and assessed all existing scientific studies regarding the identification of the royal mummies.

A geneticist (Bouwman) supported him in the assessment and a MD (Rühli) considered the finding from a medical point of view. The first author wrote the manuscript almost alone.

Introduction

The second paper focuses on the attempts of identifying the Royal mummies, limited to the more controversial 18th dynasty. I tried to collect all available studies and data since the time of their discovery until 2016. The paper is therefore a synthesis of all previous studies ever undertaken on the Royal Mummies of Ancient Egypt.

The greatest pitfall we detected is the problematic focus on Tutankhamun (from which little is known for certain despite abundant research) while other royal mummies are often neglected (even if they are considered to be the truly great rulers of Egypt).

Part 2: General mummy investigation methods and limitations

The second part of the thesis presents a single and a double case of mummy studies. Serial studies are valuable, but in the end, they depend on the basic work of studying every single case carefully.

Raffaella Bianucci, Michael E. Habicht, Stephen Buckley, Joann Fletcher, Roger Seiler, Lena M. Öhrström, Eleni Vassilika, Thomas Böni, Frank J. Rühli

Shedding New Light on the 18th Dynasty Mummies of the Royal Architect Kha and His Spouse Merit.

PLoS ONE (2015) 10 (7) e0131916. doi: 10.1371/journal.pone.0131916. eCollection 2015.

(Bianucci et al. 2015)

Direct link: Kha and Merit

Statement

Original parts of the work: The mummies of Kha and Merit had been studied before. As the previous research is either outdated or not enough focused on research questions of contemporary interest, it was agreed with the museum in Turin to re-examine the mummies.

The first author (Bianucci) and the second author (Habicht) developed the conceptualisation; Bianucci (based in Turin) made the realisation, organizing all the permissions and contacts needed. The second author (Habicht) provided all the needed scientific research material. Both equally contributed to the manuscript and the revision.

Introduction

The first study investigated the famous couple from the village Deir el-Medina (in the time of Ramses II, early 19th dynasty). They are the only mummies found in an entirely undisturbed burial (tomb TT 8) by Arthur Weigall and Ernesto Schiaparelli in 1906. Everything was in its place, even flowers at the entrance. All objects including the wrapped mummies are now in Turin, at the Museo Egizio. The mummies were never opened and will remain so (until any decay would make it necessary to open them). This fact gives certain limitations to the study, as sampling of tissue is impossible. On the other hand, the preservation is more important and as the identity of the individuals is certain and no mummies of descendants are known, a genetic profile would be of little use.

The mummies were x-rayed in the late 1960s, but the quality is inferior. In addition, not all body parts were published and one picture in the publication is in fact printed wrongly (mirrored). Especially the radiodense jewellery was problematic to achieve a clear picture of the design and number of objects on the body (Delorenzi and Grilletto 1989).

Of great interest is the preserved jewellery (in other cases mostly stolen by ancient tomb robbers): Kha, the royal architect is wearing not only the “gold of honour”-collar but is also one of the first recorded males with large golden earrings. We decided to make a special set of x-rays with higher energy (removing most of the bone structure) giving a better insight in the construction of the jewellery.
In both cases, the cause of death remains unknown. Merit, his wife, was considerably younger than Kha but died (according to historical sources) unexpectedly several years before her husband. Her ribs have fallen down to the abdomen and the spinal column is broken, turned and dislocated. We assume that this damage took place long after her death (perhaps during the transport to Italy).

Michael E. Habicht, Raffaella Bianucci, Stephen Buckley, Joann Fletcher, Abigail S. Bowman, Lena M. Öhrström, Roger Seiler, Francesco M. Galassi, Irka Hajdas, Eleni Vassilika, Thomas Böni, Maciej Henneberg, Frank J. Rühli

Queen Nefertari, the Royal Spouse of Pharaoh Ramses II:

A Multidisciplinary Investigation of the Mummified Remains Found in Her Tomb (QV 66).

PLOS ONE (2016) 11(11): e0166571. doi: 10.1371/journal.pone.0166571

(Habicht et al. 2016)

Direct link Nefertari

Statement

Original parts of the work: The remains have never been studied before, thus the entire work is original. The concept and methodology for this investigation was designed by the first author and suggested to the museum and the contributing co-authors. The manuscript was primarily written by the first author with the help from Bianucci and Galassi.

The data mining in several disciplines was provided by the many co-authors, providing valuable data and information in their field of expertise: Chemistry (Buckley), Radiocarbon dating (Hajdas), x-ray of the remains in the museum (Öhrström and Seiler), Anatomy (Henneberg), medical assessment (Böni, Galassi, Rühli, Henneberg) and support in Egyptology (Fletcher and Vassilika). The revision was done by Habicht, Galassi and Bianucci.

Introduction

During the preparation for Kha and Merit, I also found short remarks on the remains found in 1904 by Ernesto Schiapparelli in the famous tomb QV 66 in the Valley of the Kings, the final resting place of Nefertari, the favourite wife of Ramses II. The remains are a broken pair of legs, consisting of three parts with remaining wrapping, found in the debris of the destroyed burial, together with broken objects from her funeral. While they are labelled in the exhibition as remains of Nefertari, there was no report on any anthropological investigation or x-ray in 110 years. The remains were not part of the publication by Delorenzi and Griletto and only placed on an anthropological list, containing various smaller mummy parts and animal mummies (Grilletto 1991). We used the opportunity to investigate these highly interesting remains in 2014 while x-raying Kha and Merit. We formulated several working hypotheses:

- The remains are indeed those of Nefertari.
- The remains belong to an earlier burial from the 17th and early 18th dynasty from the Valley of the Queens, later washed in tomb QV 66 when the tomb was opened and plundered.
- The remains represent the rest of a later, secondary burial. During the 21st and 22nd dynasties the Valley were frequently used for burials of priests and priestesses of Amun.

The investigation was limited due to the nature of incomplete remains only consisting of a pair of preserved legs.

Most pivotal were the chemistry and the radiocarbon dating, while the genetics only revealed that the remains are highly contaminated, probably due to the fact that they were handled in the past without today's protection methods. In addition, we do not know the ancestry of Queen Nefertari and the skeletons found in KV 5 may or may not be sons of her (they are still not genetically tested) (Weeks 1999). Thus, there is currently no genetic profile to compare with and validation of any result would be impossible for the time being. The results of the radiocarbon dating are discussed in Part 4 of the thesis. The chemistry is consistent with the Ramesside period in which Nefertari lived.

Part 3: Pathologies in Ancient Egypt

Diseases of the past are of great interest for the evolutionary development of pathogens (Rühli, Galassi, and Häusler 2016; Ruffer and Moodie 1921). Among the first diseases found in mummies is Schistosomiasis by Ruffer (1910). The third part of my thesis focusses on diseases and other diagnosed pathologies.

Francesco M Galassi, Maciej Henneberg, Wouter de Herder, Frank Rühli, Michael E Habicht

Oldest case of gigantism? Assessment of the alleged remains of Sa-Nakht, king of ancient Egypt

The Lancet: Diabetes-Endocrinology (2017) 5: 580-581. (Galassi, Henneberg, et al. 2017)
Direct link: Gigantism

Statement

The old reports were discovered by Galassi (who is therefore first author) and shown to the supervising author (Habicht), asking if a study could be derived from the material.
Galassi and Rühli and de Herder addressed the medical aspects of the paper, while the statistical analysis was made by Henneberg and Habicht (relying on previous data collections by Habicht, e.g. the body height paper listed above). The data mining was done by Habicht, Henneberg and Galassi, while the conceptualisation and manuscript writing was done by Galassi and Habicht. The revision was mostly done by Galassi.

Introduction

Francesco Galassi was the discoverer of the old reports on Sa-Nakht by Myers and Garstang (Myers 1901; Garstang 1903). The remains were attributed to Sa-Nakht (older name reading Hen-Nekht), an ephemeral King of the 3rd dynasty. My contribution was the search for biographical and chronological information on King Sa-Nakht: Only few historical records testify the existence of this King: two rock reliefs in the Wadi Maghara (Sinai) and seal imprints on the northern temple of the Djoser-Pyramid-complex and additional records from Elephantine in the south of Egypt. He certainly ruled over all Egypt as the distribution of the testimonies imply and the fact that the two rock reliefs show him with the northern red crown and the southern white crown.
His genealogical position within the dynasty is uncertain (Schneider 1996, 380–381). He may have been the founder of the dynasty (Incordino 2007, 2008), ruling before King Djoser, the builder of the first Pyramid or he ruled after Djoser. Some experts equate Sa-Nakht with the King Nebka (von Beckerath 1999; Wilkinson 2001).

John Gastang discovered the skeletal remains of a man in the Mastaba K2 near Beit Khallaf. The remains of the man are described to be very tall, above 187 cm by Myers (Myers 1901). The remains were connected with the anecdote by ancient writer Manetho, who described a late 2nd dynasty king to be very tall, called Sesochris (Garstang 1903, 19) or Mesochris (Hannig 2009, 1256, No 5; Schneider 1996, 205 and 406). Today the tomb of King Sa-Nakht is considered to be unknown, and one might attribute an unfinished complex west of the Djoser complex to Sa-Nakht (Helck 1987, 20–21). It is far from certain, if the remains of Beit Khalaff are those of King Sa-Nakht, but for the medical assessment of a potential case of gigantism, it is less important if this man was a King (Incordino 2008) or a high ranking official and part of the Royal family (Grimal 1992).

Francesco M. Galassi, Michael E. Habicht, Frank J. Rühli, Stefano De Carolis

A Unique Case of Stroke and Upper Limb Paralysis in a Mid-18th Century Natural Mummy.

Circulation Research, 2017, Vol. 121 (4), 338-340. (Galassi, Habicht, et al. 2017)
Direct link: Case of Stroke

Statement

The entire work is original, as the mummy was never investigated before. The case was discovered by F. Galassi in Rimini (Italy) and therefore he is first author. The paper is included in the thesis, as the investigation is of great importance for the diagnosis of mummies from ancient Egypt. M. Habicht supported the investigation in situ (subsequent dissection of the mummy for further investigation). Galassi and Habicht made the historical research and the manuscript. The paper demonstrates the approach and method used by our research group and is a pivotal element of Part 3.

Introduction

The widespread existence of atherosclerosis (narrowing of the arteries due to the build-up of plaques) in antiquity and in Ancient Egypt was demonstrated by the Horus study, investigating a larger range of mummies (Finch 2011; Thompson et al. 2013; Clarke et al. 2014). Atherosclerosis is a so-called civilisation disease and today among the most frequent causes of death.

A similar and often attributed disease is the hardening of the walls of arteries (known as arteriosclerosis) and the Möckeberg's sclerosis (where only the middle wall, the "tunica media" of arteries in the extremities is thickened, not causing the blockage and therefore clinically not relevant).

While such atherosclerosis was found in several Egyptian mummies, e.g. King Merenptah (Shattock 1909) and also suggested for the tibial artery of Queen Nefertari (Habicht et al. 2016, 8, Fig. 10), we do not know, if these disease burdens actually lead to the death of the individual or not.

A recently investigated, natural mummy from the 18th century in Italy allowed for the first time a certain diagnosis and the determination of the cause of death due to a combination of medical investigation and the existence of historical documents, indicating that the priest suffered a stroke and later died in relation to it.

The monoliteral paralysis is supported by the unilateral gryposis of the left hand, indicating that the priest experienced a stroke (apophenic illness) as documented in the historical records. The document establishes a causal link between this stroke and the declining health of the priest, causing his demise from clerical functions. The degree of monolateral gryposis of the mummy's left hand exceeds the usual contractions of rigor mortis and, more important, the contralateral right hand lacks any such alteration. The combination of paralysis preserved in the mummy and the documentation of pre-existing stroke lead to the proposal, that the priest actually died of a stroke, making him the oldest demonstrated paleopathological patient of stroke with lethal demise.

Genetic analysis of his potential genetic risk factors is ongoing and cannot be answered for the time being.

Francesco M. Galassi, Michael E. Habicht, Frank J. Rühli

Poliomyelitis in Ancient Egypt?

Neurological Sciences, 2016, Vol 38 (2), 37 (Galassi, Habicht, and Rühli 2016)

Direct link: Poliomyelitis

Statement

This letter to Neurological Sciences is a spin-off from my research on the royal mummies and the diagnoses made by various studies. The concept of the paper was made jointly by Galassi and Habicht. My contribution was the research on the artwork and the diagnoses made to the mummy of King Siptah, who allegedly had suffered from poliomyelitis. The manuscript was jointly written by Galassi and Habicht. As the topic and aim is medical, Galassi was chosen to be first author.

Introduction

The existence of poliomyelitis in Ancient Egypt is proposed, based on artistic representations and one famous royal mummy. The stele of a priest called Ruma (or Rem), Copenhagen, Ny Carlsberg Museum ÆIN 0134 from the 19th dynasty is generally considered to be one of the first representations of a

poliomyelitis victim (Leca 1986, 223). However, we do not know, what actually caused the shortening of the leg, it could have been poliomyelitis or a congenital defect.

Another possible example from the 18th dynasty is the famous relief "Royal couple in the garden" in Berlin (Egyptian Mus. Inv. 15000) showing a late Amarna couple of a king and a queen is also often quoted as typical representation of a poliomyelitis victim with shortened leg using a cane (Leca 1986, 193). Not only the identity of the couple is uncertain (Habicht 2011) due to the lack of any inscription, but it remains entirely unclear if the relief depicts either Akhenaton and Nefertiti or Smenkhkare and Meritaton or Tutankhamun and Ankhesenamun. Furthermore, it is even possible that the relief is a counterfeit or the clumsy work of a lesser artist (Eaton-Krauss 2002; Krauss 2009). Thus, identifying specific diseases in Ancient Egyptian art is extremely uncertain.

Pharaoh Siptah was the son of Sety II and a secondary Queen, probably a Syrian woman Sutiraja, depicted on a relief (Louvre E 26901). He is highly interesting for medicine, since his left foot is severely deformed and the leg is shortened. In the past it was considered to be a club foot (*Pes equinovarus)* and after the x-ray investigation the overall shortening of the leg and the atrophy of soft tissue was interpreted as neuro-muscular disease (J. E. Harris and Weeks 1973). Otherwise Siptah was healthy and his dentition was in good condition, since he died young in his late teens or early twenties (J. E. Harris and Weeks 1973). Leca observed that in the case of Siptah that only the foot is deformed, without shortening of the leg bone (Leca 1986, 222) and favoured a congenital deformation, which as much as mummification-caused modifications should also be considered as differential diagnoses (Galassi, Habicht, and Rühli 2016). A similar case is the female mummy KV 21 A, with a similar shortened and deformed right foot, here identified as club foot (Hawass et al. 2010; Hawass and Saleem 2016). The paucity of potential cases leads to the conclusion that without further evidence, the existence of poliomyelitis in Ancient Egypt is still speculative.

Michael E. Habicht, Patrick E. Eppenberger, Francesco M. Galassi, Frank J. Rühli, Maciej Henneberg

Queen Meresankh III – The oldest Case of Silent Sinus Syndrome

Anthropology. International Journal of Human Diversity and Evolution (CZ), Vol. 56 (1) 2018. https://doi.org/10.26720/anthro.17.09.25.2

(Habicht et al. 2018)

Direct link: Meresankh III

Statement

Discovery of the case in archaeological literature was made by Habicht and shown to Prof. Henneberg without giving any information on the individual for an anatomical assessment with the clear verdict that the skull appears to be pathological. The research for finding an explanation was done in the team (Habicht, Henneberg, Galassi, Eppenberger and Rühli). Patrick Eppenberger provided the team with the 3D reconstruction, based on the anthropometric measurements done by Henneberg, Habicht and Galassi (independent measurements to avoid bias). The manuscript was written as team work: Habicht provided the Egyptological background on the biography of Queen Meresankh III, her ancestry and descendant and the general writing of the paper (conceptualisation). The data mining for anthropological comparison was based on the Howell' database and a large collection of data by Habicht (yet unpublished). The revision was minimal as the manuscript was accepted practically without change.

Introduction

During the research on the new Sothis-date (see Part 4) I also discovered the autopsy report of Queen Meresankh III (Dunham and Simpson 1974). The unusual shape of the skull was presented to Prof. Henneberg and was estimated to be clearly pathological. We applied a differential diagnosis on the skull and excluded a variety of disorders, leaving only the rare Silent Sinus Syndrome. The first medical description dates back only to 1964 and the term was coined in 1994 (Soparkar, Patrinely, and Cuaycong 1994).

This syndrome is a biomechanical modification of the skull after the collapse of the maxilary sinus and does as far as it is known, not manifest in genetics. In addition, genetic predisposition is not known.

Part 4: Chronology

Chronology is the backbone of history and archaeology and of vital importance to many other disciplines. Most ancient Mediterranean Bronze Age cultural chronologies are more or less dependent on the chronological models of ancient Egypt. Several such models for Egypt exist, namely the so-called high and low chronologies: The basic challenge is in the Eygptian year counting, as the years were counted by regnal years (year x of king x). When the king died, the year count started again with year 1 of the successor. Therefore, it is essential to know the highest recorded year of every king and potential co-regencies (von Beckerath 1997). Implementing entriely different methods, such as radiocarbon dating, dendrochronology and recorded astronomic events produced additional fact and information but increased the compelxity of chronological models (Bronk Ramsey et al. 2010; Quiles et al. 2012). Among all chronological problems, the Old Kingdom has a special place, as the Egyptians used a very special year count, distinguising between a "year of the event" and a "year after the event" (Gardiner 1945). The ratio between them does not support the long proposed "bi-annual" count (c. 50:50 ratio), as the ratio is more towards 70:30 (Nolan 2003, 2008; Der Manuelian and Schneider 2015). Published radiocarbon dates of the Old Kingdom were pointing towards a high chronology model (Hornung et al. 2006; Dee et al. 2009).

Michael E. Habicht, Raffaella Bianucci, Stephen Buckley, Joann Fletcher, Abigail S. Bowman, Lena M. Öhrström, Roger Seiler, Francesco M. Galassi, Irka Hajdas, Eleni Vassilika, Thomas Böni, Maciej Henneberg, Frank J. Rühli

Queen Nefertari, the Royal Spouse of Pharaoh Ramses II:

A Multidisciplinary Investigation of the Mummified Remains Found in Her Tomb (QV 66).

PLoS ONE (2016) 11(11): e0166571. doi: 10.1371/journal.pone.0166571

(Habicht et al. 2016)

Direct link Nefertari

Statement

See statement above. The idea to radiocarbon date the remains was suggested by Habicht (creating an additional default criteria). The radiocarbon dating work was done by Irka Hajdas and her team members' Radiocarbon dating laboratory (Ion Beam Physics, ETH, Zurich). The report on the dating in the paper was written by Hajdas and Habicht.

Introduction

The remains of Nefertari were found in the debris aside broken gilded coffins and a smashed stone sarcophagus, carrying only her name (Willeitner and Schmidt 1997). Traces of later or additional burials are absent. The chemical analysis of the legs found revealed a mummification method, which is typical for the Ramesside period, using dry natron, resin, and animal fat, but no substantial use of bitumen as in later periods (Colombini et al. 2000; Buckley and Evershed 2001; Harrell and Lewan 2002; Habicht et al. 2016).

The tomb was flooded in ancient times and intruding soil contaminants may indeed be one of the reasons that the radiocarbon age appears inconsistent with other chronological data. Another explanation may raise some questions regarding the cultural chronological models and their relation to absolute chronology, as the case of the Thera-eruption (Friedrich et al. 2006) or recently published data on animal mummies demonstrate (Wasef et al. 2015). This chronological discrepancy between cultural models and chronometric dating of organic remains has been observed before and for different periods of Egyptian history (Bietak et al. 1992; Bietak 2003; Dee et al. 2009; Shortland et al. 2013; Gautschy et al. 2017).

We obtained the following radiocarbon results for bone collagen extracted from the legs found in the debris of tomb QV 66:

OxCal v4.2.4 (Bronk Ramsey, Scott, and van der Plicht 2013); r:5. IntCal13 atmospheric curve (Reimer et al. 2013) as published in the study on Nefertari (Habicht et al. 2016). ETH-67019 R_Combine (3244,17) as published in Plos One (Habicht et al. 2016)

68.2% probability	1531BC (65.1%) 1497BC
	1469BC (3.1%) 1465BC
95.4% probability	1607BC (9.3%) 1582BC
	1561BC (1.2%) 1553BC
	1546BC (69.0%) 1491BC
	1485BC (15.8%) 1450BC

Using conventional cultural chronologies, most of the dates would fall into the 17th dynasty, the late Second intermediate Period) with a distinctly different mummification style (oily and often evaporating an unpleasant odour), which is not the case for the remains from QV 66. The most recent radiocarbon dating range (1485 – 1450 BC) is the most consistent in relation to other data and would conventionally fall in the earlier 18th dynasty.

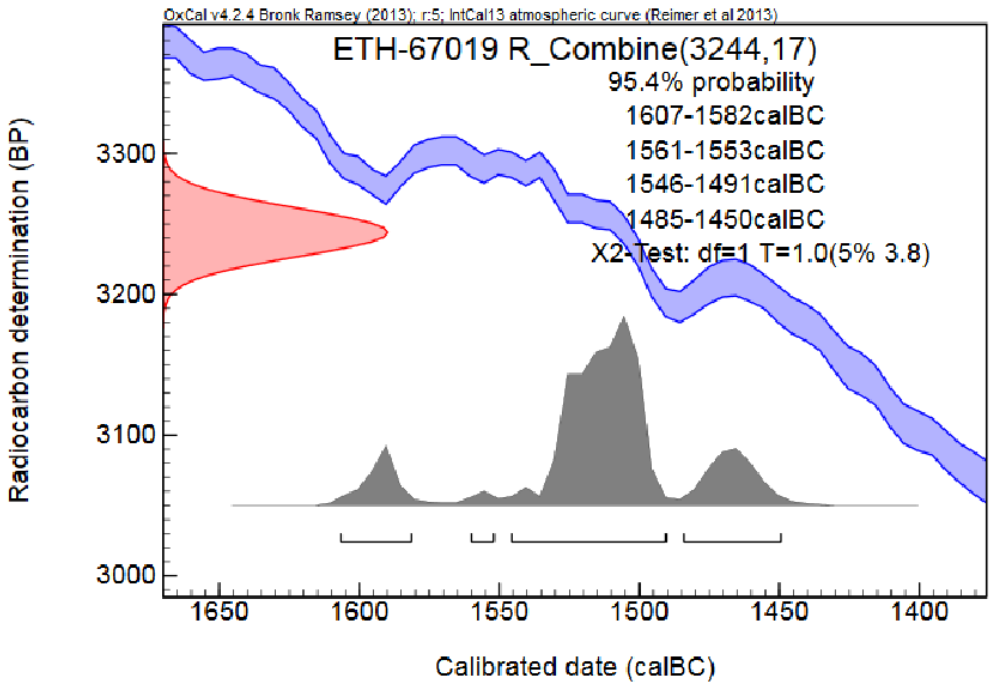


Fig 13. Calibrated result of the radiocarbon dating. (Habicht et al. 2016)

Michael E. Habicht; Rita Gautschy; Renate Siegmann, Daniela Rutica; Rainer Hannig

A New Sothis Rise on a Small Cylindrical Jar from the Old Kingdom.

Göttinger Miszellen (2015) 247: 41-50. (Habicht, Siegmann, et al. 2015)

Direct link: Sothis

Statement

The paper is entirely original as it presents a new discovery that went unnoticed for more than three decades after the auction sale in 1981. The concept for the first publication was made by Habicht, including the realisation and writing of the manuscript. A revision of the paper was not necessary as it was accepted as submitted. The astronomical dating was made by Habicht, based on the published studies by Rita Gautschy and supervised by her. The translation was done be all the researchers and supervised by Prof. Hannig.

Rita Gautschy and Michael E. Habicht, Francesco M. Galassi, Daniela Rutica, Frank J. Rühli, Rainer Hannig

A new astronomically based chronological model for the Egyptian Old Kingdom.

Journal of Egyptian History (2017) 10(2): 69-108. (Gautschy et al. 2017)
Direct link: Chronology

Statement

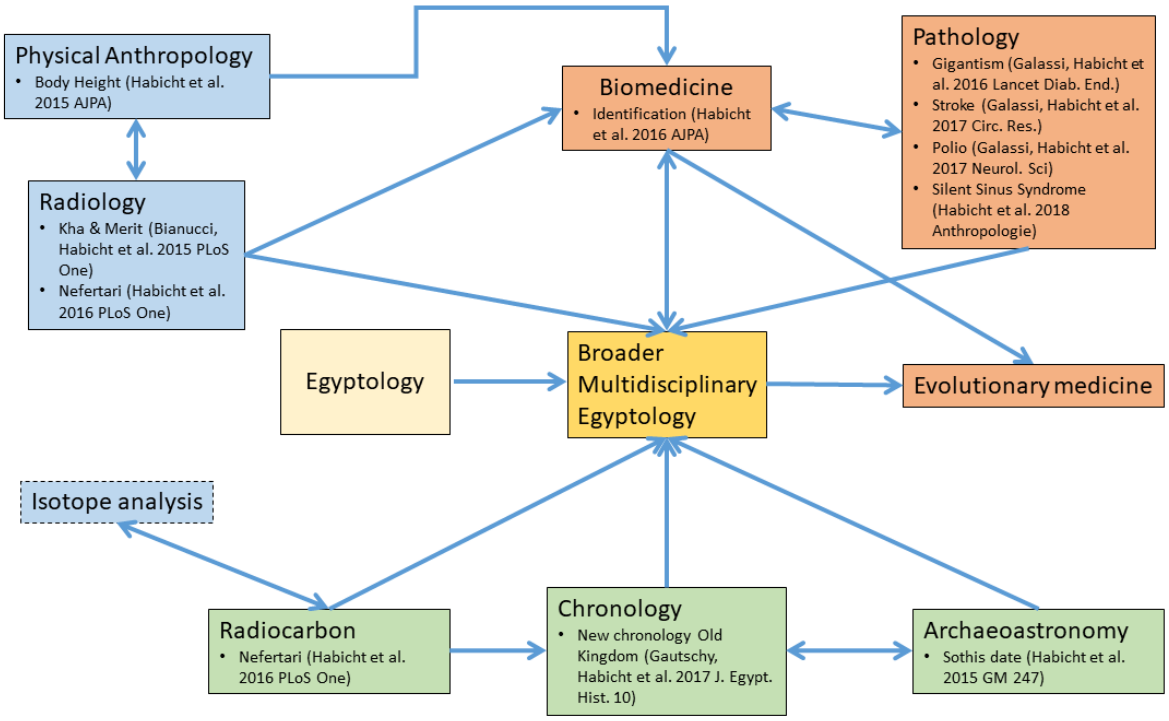
After the publication of the material, I approached the other authors with the idea of using the new Sothis-date as starting point for developing a new astronomical chronology for the Old Kingdom.
Habicht and Gautschy are the main authors, as they both collected all reported contemporary dates from the Old Kingdom known in scientific literature. The basic conceptualisation was done by Habicht, while the actual embedding of the dates in the astronomical model was done by Rita Gautschy. The idea of applying the concept of a Metonic cycle to explain the 3-3-2-pattern of the year of event and the year after the event was suggested by Habicht and mathematically tested by Gautschy. The manuscript was written by Gautschy and Habicht. The final formatting and revision were made by Gautschy.

Introduction

Both publications are linked together, the first one is the report on the discovery of the new Sothis-date from the Old Kingdom, the second the derived new chronology model based on astronomical records and year counts, length of reigns following closely the Turin Royal Canon (Gardiner 1959; Malek 1982). In addition the calibrated radiocarbon dates from the Old Kingdom were implemented in the model (Bonani et al. 2001; Hornung et al. 2006; Bronk Ramsey et al. 2010).
The new Sothis date was discovered 31st July 2014 by pure coincidence, as Prof. Rainer Hannig, his wife Daniela Rutica and myself were visiting the newly exhibited donation of late Professor Peter A. Kaplony. The inscription is clearly readable and refers to a heliacal rise of Sirius after a time of invisibility of 70 days in Egypt.
Taking different observations (arcus visionis) into account, the given date refers to a time window between 2419 and 2406 BC. This date range falls in the time of the Old Kingdom, making it the oldest Sothis-date for ancient Egypt and (probably) the oldest astronomically defined date in the world.

Discussion

The aim of this section is to discuss the impact of the presented papers and their contribution to the improved understanding of the ancient Egyptian civilisation from a bioarchaeological perspective.



The graphic illustrates the different fields of research employed, all contributing to the field of Egyptology and broaden the view on ancient culture as well as for the understanding of diseases in the discipline of evolutionary medicine.

Contextual statement

The different papers contributed in various disciplines: The paper on body height (paper 1) contributed in the field of physical anthropology by completing our knowledge. Previous studies focussed on the predynastic and early dynastic period (Robins and Shute 1986; Zakrzewski 2003) or on the royal family alone (Robins and Shute 1983). Now the data pool on the body height in Ancient Egypt is considerably larger and combines the general population and the royal families. The discovery of the consanguinity in the royal families was an unexpected by-product, confirming theories from the field of history and social sciences.

The results won from the multidisciplinary approach in case of the investigation of Kha and Merit and especially for Nefertari contributed new information to biomedicine and Egyptology as well (paper 3 and 4). The aim of such research is demonstrated by the study on the identification of the royal mummies (paper 2): The multidisciplinary contextualisation opens entirely new approaches and supports our knowledge of history.

The studies on diseases and pathologies are of great value for history and medicine alike (papers 5-8) as they expose potential pitfalls and – on the other hand – present new evidence for rare syndromes (gigantism and the silent sinus syndrome). Such studies are valuable not only for Egyptology but also for evolutionary medicine, as they present very old or even the oldest known case.

The papers published in the field of chronology (papers 9-10) allowed for an astronomical dating of Egyptian dynasties in the third millennium BC. They present and use the potential of the oldest unambiguous so-called Sothic date known so far.

Physical Anthropology

In recent years, anthropometrics have been successfully used for investigating evolutionary trends of mankind (Hermanussen et al. 2014; Bentham et al. 2016). Inspired by research projects done by the ZEM (Centre for Evolutionary Medicine, the forerunner of today's IEM), we decided to test the feasibility of body height development in Ancient Egypt. The detection of statistical hints towards widely practiced incest in the royal family was an unexpected by-product. It confirmed independently and mathematically corroborated facts already suspected by historians and social science (Bixler 1982; Scheidel 1996; Jones 2001; Ager 2005; Frandsen 2009).

Mummy Investigation

Case studies associated with the investigations of individuals provide the basic material from which larger serial studies can be derived. The case of Kha and Merit (mid-18th dynasty, c. 1450 BC) is to a certain extent unusual because the mummies were never opened and this will remain the case until restoration is needed. They were x-rayed in the late 1960s but the quality of the pictures is deficient in relation to the current scientific standards (Delorenzi and Grilletto 1989). Some years ago, the mummies were CT-scanned, but the quality of published pictures are so inferior that the pictures are of no diagnostic value (Martina et al. 2005). Our contribution therefore is a set of digital x-rays of high quality with public accessibility as they are published as open-source (also having a scientific popularisation of our research in the public perception).

Our research involving the pair of legs found in the tomb of Queen Nefertari (early 19th dynasty, conventionally dated c. 1250 BC) is the first scientific investigation and description and will remain the basis for any further research.

The results provide additional support for the hypothesis that the famous QV 66 was actually the tomb used to inter Queen Nefertari and that she was about 40 - 50 years old, very tall and slim. The description correlates quite well with her artistic depiction, showing her as very tall and slender woman.

Further investigations on the legs are recommended, e.g. Micro CT-scan to determine the true cause of the calcifications and if one day available a genetic comparison with the remains found in KV 5 (if the genetics can deal more adequately with the contamination).

Pathologies

The identification of pathologies in ancient human remains is of great value for medical history, studies addressing evolution of diseases and for the understanding behavioural variability in past societies.

The case of Sa-Nakht (3rd dynasty, c. 2700 BC) and the suggested gigantism provides an important contribution to questions related to the origins and social contexts of such conditions. In addition, it expands the number of cases in the Old World and provides comparative materials in relation to a previous focus on these conditions in the Americas. It also demonstrates the usefulness of re-assessing old reports in search for new information.

The mummy with stroke is probably the oldest case worldwide to date, where not only cardiovascular diseases were found, but they were also coherently connected with the actual cause of death. Due to the lack of medical and historical records of this kind, it is not very likely to find a similar conclusive case for previous times, including Ancient Egypt, where atherosclerotic changes have however been found in mummies and description of cardiac disease and death have been seen in ancient hieroglyphs and medical papyri.

The other, shorter papers, are a spotlight on the potential risks of retrospective diagnosis: While the presence of bilharzia, atherosclerosis and malaria in Ancient Egypt have been demonstrated previously, other suggested illnesses are in fact questionable, e.g. the alleged "first victim" of smallpox (variola): in the late 1970s the WHO presented the mummy of Pharaoh Ramses V (20th dynasty) as the first known individual to have suffered and died of smallpox. A new study showed, that this diagnosis might be wrong as the reported strains of smallpox found in natural mummies of the 17th century AD only reach back to the Renaissance (Duggan et al. 2016). For the antiquity we do not know, if there were different strains of smallpox or the pustules on the body of Ramses V are caused by a different disease.

This new finding is somewhat intimidating, as it might be possible, that a newly evolved smallpox may return to humankind in the near or distant future. Hence, investigating the mummy of Ramses V would be of greatest epidemiological importance to understand the past of disease and to be prepared for the future.

The same question applies to the existence of poliomyelitis in Ancient Egypt. Artistic works like the stele of Ruma (18th dynasty, c. 1450 BC) and the crippled foot of Pharaoh Siptah (19th dynasty, c. 1190 BC) are often presented in archaeological literature of early cases of poliomyelitis. While art will remain an uncertain ground for such diagnoses, as the Egyptian art is not realistic, only a genetic investigation of Pharaoh Siptah may answer this unsolved question. Based on the known data, our paper cannot confirm the presence of poliomyelitis in Ancient Egypt.

The skull of Queen Meresankh III proposed an entirely new diagnosis of a rare syndrome. The oldest cases in medical literature date back to 1964 AD only. As Meresankh III is firmly dated in the late 4th dynasty (to c. 2570 BC), we suggest a much older age for this syndrome. It would be beneficial for other researchers to search other cases in historical collections or at least also consider less frequent diseases or syndromes in differential diagnoses.

Chronology

Spatial and temporal data are essential components of archaeological research. Accurate chronologies are required to establish behavioural variability in past societies. Most ancient Mediterranean Bronze Age cultural chronologies are more or less dependent on the chronological models of ancient Egypt.
Several such models for Egypt exist, namely the so-called high and low chronologies (Bietak et al. 1992; von Beckerath 1997; Hornung et al. 2006). Chronology in Ancient Egypt is often investigated in reversere order (von Beckerath 1997), as the Late Period is quite certain due to dated synchronisms with neighboring cultures. The problem starts in the Third Intermediate Period where the lengths of reigns are debated and the main synchronism is often the Bible (which is dependent on the Egyptian chronology - thus a circular argument).

The contribution for the New Kingdom chronology

For the Egyptian New Kingdom (conventionally dated to c. 1550-1070 BC), the chronological models are based on historical and astronomical data and some Egyptian wiggle-matched radiocarbon data. In the end, they produce problems if they are combined with the radiocarbon dating of the Thera eruption in the Mediterranean, which is usually dated 1627/1600 BC (Friedrich 2013).
What does the super-massive erruption of Thera mean?
Is it a naturalistic explanation for many theories as the Exodus plagues or Atlantis and the effect on nearby civilisations? The topic is a perfect playground for speculation and a problem for science (Galanopoulos and Bacon 1978; M. Harris 2013).
The eruption is paradoxically interlinked with the early New Kingdom in Egypt: late Minoan ceramics (LM 1A) was the latest ceramics found in Acrotiri, abandoned when the eruption took place and also found in Egypt in the early New Kingdom.
The ash cloud mostly seems to have been blown to Rhodes (M. Harris 2013). In the past, the eruption was dated 1450 BC, fully consistent with the early New Kingdom in Egypt. The pumice, built during the eruption was also found in Egypt in the time of Pharaoh Ahmose I, conventionally dated (early 18th dynasty, c. 1554-1525 or 1547-1522 BC) (von Beckerath 1997, 121–123) and even with later Kings, e.g. Thutmose III (mid-18th dynasty, c. 1479-1425 BC) (von Beckerath 1997, 126).

The Minoan Culture did fall around 1450 BC, but the Minoan Eruption of Thera seems not to be the main cause. The eruption is often dated by archaeological arguments to c. 1530 BC and the reign of Ahmose I (Kutschera et al. 2013). However, a new discovery produced again an odd result (Hammer et al. 1987; Friedrich et al. 2006; Friedrich 2013; Kutschera et al. 2013; Bietak 2014): Most notable is the olive tree (found in 2003): the tree was buried during the eruption and was radiocarbon dated c. 1600 – 1627 BC (Friedrich et al. 2006). The discrepany of c. 150 years is obvious and was also observed in archaeological sites in Egypt, most notable in the site Tell el-Daba (Avaris) (Kutschera et al. 2013). Organic samples systematicly date c. 120 years older than expected.

This earlier dating is additionally supported by results from mummies, also often dating systematically 150-200 years older than expected (Wasef et al. 2015; Habicht et al. 2016). Other data match well with the lower historical model, e.g. organic material from Amarna (Quiles et al. 2012) or perhaps the shipwreck of Uluburun, that carried a ring with the name of queen Nefertiti and hence has to be dated mandatory to post-Amarna times (S. W. Manning et al. 2009). The ship may have sailed some generations after the time of Queen Nefertiti. Hence, the various data disagree by about 150 years.

The radiocarbon dating of the remains attributed to Queen Nefertari provide interesting additional information to the ongoing debate (Habicht et al. 2016).

The published result seems odd:

ETH-67019 R_Combine (3244,17)

68.2% probability

1531 BC (65.1%) 1497 BC

1469 BC (3.1%) 1465 BC

95.4% probability

1607 BC (9.3%) 1582 BC

1561 BC (1.2%) 1553 BC

1546 BC (69.0%) 1491 BC

1485 BC (15.8%) 1450 BC

If one applies conventionally accepted chronological models, the remains would either date in the late 2nd Intermedite Period or the early New Kingdom. All others facts de-facto exclude such a dating and the result being "too high" is fully consistent with other mummies.

This chronological discrepancy between cultural and historical models and chronometric and other scientific dating methods has been observed before and for different periods of Egyptian history (Bietak et al. 1992; Bietak 2003; Dee et al. 2009; Shortland et al. 2013; Gautschy et al. 2017). The inherent uncertainties associated with radiocarbon dating (e.g. an 80-year range at 2-sigma is present for lab measurements with only a ± 20-year error) means that chronologies derived from historical documents, gravestones or technological/stylistic variability are often more accurate than those based on chronometric methods. Currently the research group at the Institute of Evolutionary Medicine at the University of Zurich is testing the effect of mummification agents on radiocarbon determinations in collaboration with the ETH (Eidgenössische Technische Hochschule / Federal Technological University) in Zurich. A pig that died in December 2016 in the Veterinary Hospital in Zurich was used for the experiment. The internal organs (liver, lung, stomach and intestines) were mummified in natron according to Egyptian embalming practices. After the embalming, the mummified tissue was treated with different substances, including spruce resin, beeswax and bitumen in several combinations.

When the pig tissue samples (ETH-80016-80022, -230 BP (2016 AD) were dated by radiocarbon, they returned calibrated ages of various age (see table below). The agents had indeed an effect on the dating, even after complete cleaning (-157 BP) and acid-base-acid (ABA) cleaning (-41 BP) in case of treating the tissue with resin and beeswax.

Sample	Descr.	Cleaning	C14 BP	±1σ	F14C	±1σ	δC13	C/N
Pig			**-230**					
ETH-80016	Natron - 50% beeswax & 50% resin	Inner part, no cleaning	-132	22	1.01700	0.00300	-24.1	5.38809893
ETH-80016	As above	Inner part, full cleaning	-157	22	1.02000	0.00300	-25.2	3.83389693
ETH-80016	As above	With resin, only ABA	-41	21	1.00500	0.00300	-28.5	59.7204624
ETH-80016	As above	With resin, full cleaning	-140	22	1.01800	0.00300	-22.5	3.79903247
ETH-80016	As above	With resin, 2x Solhelt, ABA	-128	22	1.01600	0.00300	-25.8	3.74452414
ETH-80018	Natron - 25% beeswax, 25% resin, 50% bitumen	Inner part, no cleaning	-164	22	1.02100	0.00300	-25.3	4.56994167
ETH-80018	As above	Inner part, full cleaning	-183	22	1.02300	0.00300	-28.6	3.69207324
ETH-80018	As above	With resin, only ABA	2983	24	0.69000	0.00200	-28.5	87.3409355
ETH-80018	As above	With resin, full cleaning	390	23	0.95300	0.00300	-29.1	4.03659662
ETH-80018	As above	With resin, 2x Solhelt, ABA	-110	22	1.01400	0.00300	-24.0	3.72014554
ETH-80019	Pure substance beeswax		161	22	0.98000	0.00300	-26.1	874.541249
ETH-80020	Resin (picea)		-334	22	1.04200	0.00300	-28.1	1094.87917
ETH-80021	bitumen		9263	30	0.31600	0.00100	-30.5	128.168407

Table: Preliminary results from an embalming experiment (excerpt): The place where the sample was taken plays a pivotal role, also the cleaning method and the impact of material used in the embalming resin. The beeswax was found to be contaminated with old paraffin, the bitumen has a visible impact on the results as it contains almost no ^{14}C anymore.

The most profound impact was associated with the use of bitumen in the mummification process. Being a fossil carbon, bitumen has radiocarbon ages of older than 50,000 years because it no longer contains any ^{14}C. When only the inner part of the tissue was sampled, the radiocarbon age was 74 BP, but outer tissues exposed to bitumen returned dates of up to 3000 BP. Contamination of the tissues with old carbon associated with the bitumen would produce these results. The investigation is still ongoing and will need further corroboration but it has the potential to yield an explanation for the often-observed higher dating of mummified tissue (Galassi et al. 2018). Therefore, research showing products used in mummification process is essential when radiocarbon dating is undertaken.

The contribution for the Old Kingdom chronology

The Middle Kingdom was defined for a long time by the Sothis-date from Ilahun (Borchardt 1899) and the recorded lunar dates (Gautschy 2011). Recently, dendrochronological analyses of tree ring samples from a coffin and wood from a funeral boat near the pyramid of King Senwosret III (12^{th} dynasty, c. 1850 BC) point again to a higher chronological model for the Middle Kingdom (S. Manning 2014). This fact is essential for the correct placing of the Old Kingdom.

The chronology of the Old Kingdom was always difficult, caused by the special year count: see our paper (Gautschy et al. 2017) and the studies of John S. Nolan (Nolan 2003, 2008, 2015).

We were incredibly fortunate to discover the oldest Sothis-date from ancient Egypt in 2014 and the opportunity to derive a complex chronological model.

Our new astronomical study opens the possibility to move the entire Egyptian chronology to a high model without causing a historical paradox (e.g. the collision of periods or unexplainable gaps in history).

Conclusion and Recommendations

Archaeology is a never-ending quest for new facts and conclusions. It is reasonable to reflect on possibilities to improve the methods. As a combined sampling and testing for radiocarbon and other isotopes will be the future “gold standard” in chronology, this method should be adapted for future projects.

In the following section, I summarise the implications of the results of my published research as represented in the case studies above for future investigations and research designs involving mummies. In most cases, investigations should include:

- Historical background research
- Associated archaeological materials
- Inscriptions

- Measurements and physical anthropology
- X-ray or/and CT-scan
- Radiocarbon dating
- Stable isotope analyses
- Medical diagnosis
- Genetics

The historical background research should be at the very beginning of every bioarchaeological research project. By checking the historical known information and the existing literature, one can assess the potential and pitfalls of a project.

A careful study of the existing archaeological materials in combination with the targeted human remains will provide the base for any subsequent line of inquiry (Berry 2012).

Physical Anthropology

Further measurements of all mummies in various collections should be undertaken, either by measuring the overall length (which I found quite reliable, the accuracy is within a range of 2-3cm) or by employing an even better method of measuring the long bones (femur, tibia and humerus) according to standardized methods as described by standard reference literature, using x-ray and CT-scan pictures (Martin and Saller 1957; Buikstra and Ubelaker 1994).

In the past, such general and useful measurements were regularly performed with great care. After the 1960s, they were sometimes abandoned in favour of x-ray technology.

Detailed physical measurements of the human remains and accurate descriptions are highly important as demonstrated by the case of the now missing remains of Queen Mutnedjmet (Strouhal 1982). Eugen Strouhal provided the initial physical documentation for the remains and this has been invaluable to subsequent research.

Radiological investigation is also recommended whenever possible, as the x-ray technology generates a plethora of additional, medical information on health, age, stress-markers (Harris lines) and embalming methods.

Radiocarbon dating of human remains should become the general standard for every bioarchaeological investigation, avoiding misinterpretation of secondary burial from an entirely different time to be the targeted remains of a historical figure. In the future, a combined sampling for radiocarbon and stable isotope analysis will be the ‘gold standard’. The additional data provided by the stable isotopes helps to assess the influence of freshwater and fish diets on radiocarbon ages (fish contain less ^{14}C and make the sample appear older) and provide valuable information about residence and mobility during different stages of life (Pate 1994, 2008; Hajdas et al. 2014; Wasef et al. 2015). I personally strongly suggest, that so-called chronologically certain organic remains (e.g. historically dated mummies, or even better,

original linen wrapping if available) should be radiocarbon tested to assess the accuracy of the chronological model and for calibration of the INTCAL calibration curve (Reimer et al. 2013). Additional research addressing diagenesis in mummified tissues will employ minimally-invasive femoral bone cores (Owen 2000) on unwrapped and wrapped mummies to further examine the effects of the mummification process on changes in bone collagen isotopic values from the outer femur to the inner femur.

Archaeological chemistry is also helpful to interpret mummified remains and essential for radiocarbon dating as the case of Nefertari demonstrated. The use of materials changed much during the time period and in combination with the method of mummification, chemistry can support the archaeological dating (Buckley, Stott, and Evershed 1999; Buckley and Evershed 2001; Buckley, Clark, and Evershed 2004; Buckley 2014; Buckley and Nissenbaum 2013; Nerlich et al. 2014).The use of liquid natron solution instead of natron powder during the later parts of the 18th dynasty is still debated (S. A. Buckley 2014). In case of Kha and Merit, the use of liquid natron is suspected, based on the facts that the internal organs are still in the body but well-preserved, the same for the brain tissue. The brains are little shrunken but otherwise in good shape. As such soft tissue is prone for putrefaction within a few hours, it is suspected with good reasons that non-invasive mummification methods with liquids must have been used (Bianucci et al. 2015). Most observed or suspected cases actually seem to date in the Amarna Period (mid to late 18th dynasty), perhaps started by the unusual mummification of Pharaoh Amenhotep III (Fletcher 2015, 215; Habicht, Bouwman, and Rühli 2016).

Selected stuffing of shrinking body parts (especially the neck) was already practiced with various materials in the later 18th dynasty in elite mummies (Saleem and Hawass 2015; Hawass and Saleem 2016).

The Ramesside Period fell back to more conventional mummification with dry natron powder but later introduced the stuffing of the abdomen with aromatic lichen and sawdust.

The next massive change in mummification technique in the 21st dynasty was not only the use of chemical agents but massive subcutaneous stuffing (J. E. Harris and Weeks 1973).

In the future, extensive isotope analysis should be included in all such investigations. In an ideal scenario, not only the archaeologist and the geneticist but also experts in Ion Beam Physic department and isotope specialist should either participate in the sampling process (or at least the sampling is following a protocol and documentation allowing the other experts to apply correct cleaning and treatment of the sample).

Medical diagnoses often open entirely new perspectives on history as this discipline can provide information not provided in historical records (the diseases and true cause of death is unknown or uncertain for many historical figures). Genetic studies employing ancient human remains are still highly

challenging and the results are often controversial (Campana et al. 2014). In the last years, the first credible results were produced, focusing on the mitochondrial genome (Schuenemann et al. 2017).
In the presented papers, genetics played a minor role due to historical circumstances, including lack of access to the required materials related to sampling restrictions imposed by museum curators. Kha and Merit are still wrapped and will probably never by opened. In addition, their identity is absolutely certain and related mummies to compare them are not be known.
The remains of Queen Nefertari were found to be massively contaminated and no profiles to compare her with are known. Her potential children, buried in KV 5 in the Valley of the Kings, have not been tested for genetics so far and their authenticity is not certain (they might be secondary burials from a much later period).
Queen Meresankh III is also an isolated case as their ancestry and children are not preserved and Silent Sinus Syndrome has no known hereditary predisposition.
The mummy who suffered a stroke is currently under additional investigation for genetic risk factors triggering cardiovascular diseases. The results are not yet known.

Ancient genetics may provide additional information regarding presence of particular diseases or relationships between individual mummies. Yet, such results need careful historical research on ancestry and descendants. Genetic studies addressing familial relations will only be instructive if related mummies are known and available for investigation or if they have been previously involved in genetic analyses.
Bioarchaeological research designs that combine a range of these independent methods will have the best opportunities to demonstrate new information about the complexities of past social and economic behaviours in ancient societies.

References

Literature quoted in the introduction, abstract and discussion. The citation program Mendeley was used to generate the additional references. In some cases, it was not possible to give the full name, as only initials are known.

Ager, Sheila L. 2005. "Incest and the Ptolemaic Dynasty." *Journal of Hellenic Studies* 125: 1–34.

Arrizabalaga, Mónica. 2015. "«Si Hay Una Cámara Secreta En La Tumba de Tutankamón Es Más Probable Que Esté Meritatón Que Nefertiti». El Egiptólogo Francés Marc Gabolde Cree Que La Momia de La Mítica Esposa de Akenatón Es La Conocida Como La Dama Joven." *ABC Cultura*, November 29. http://www.abc.es/cultura/20150929/abci-camara-secreta-tumba-tutankamon-201509281011.html.

Balaji, Nand. 2018. "Bust of Contention: Nefertiti's Sculpture Raises Issues of Race and Color—Part II." *Ancient Origins*, 11 February. http://www.ancient-origins.net/news-history-archaeology/bust-contention-nefertiti-s-sculpture-raises-issues-race-and-color-part-ii-021826.

Bentham, James, Mariachiara Di Cesare, Gretchen A. Stevens , Bin Zhou, et al. (794 authors in Total). 2016. "A Century of Trends in Adult Human Height." *eLife*, pii: e13410. doi:10.7554/eLife.13410.

Berry, Stephan. 2012. *Antike Im Labor*. Mainz: Philipp von Zabern.

Bianucci, Raffaella, Michael E. Habicht, Stephen A. Buckley, Joann Fletcher, Roger Seiler, Lena M. Öhrström, Eleni Vassilika, Thomas Böni, and Frank J. Rühli. 2015. "Shedding New Light on the 18th Dynasty Mummies of the Royal Architect Kha and His Spouse Merit." *PloS One* 10 (7): e0131916. doi:10.1371/journal.pone.0131916.

Bickerstaffe, Dylan. 2009. *Identifying the Royal Mummies. Refugees For Eternity: The Royal Mummies of Thebes*. London: SOS Free Stock; Canopus Press.

Bietak, Manfred. 2003. "Science Versus Archaeology: Problems and Consequences of High Aegean Chronology." In *The Synchronisation of Civilisations in the Eastern Mediterranean in the Mid Second Millenium*, edited by M. Bietak and H. Hunger, 22–33. Wien: Oxbow Books.

Bietak, Manfred. 2014. "Radiocarbon and the Date of the Thera Eruption." *Antiquity* 88 (339): 277–282. doi.org/10.1017/S0003598X00050389.

Bietak, Manfred, Wolfgang Helck, Jürgen von Beckerath, Rolf Krauss, Christian Leitz, et al. 1992. "High, Middle or Low? [Ägypten Und Levante, 3]." In *Akten Des Zweiten Internationalen Kolloquiums Über Absolute Chronologie . Schloss Haindorf/Langenlois, 12.-15. August 1990*. Wien: Verlag der Österreichischen Akademie der Wissenschaften.

Bietak, Manfred, and Eugen Strouhal. 1974. "Die Todesumstände Des Pharaos Seqenenre (17. Dynastie)." *Annalen des Naturhistorischen Museums in Wien* 78: 29–52.

Bixler, Ray H. 1982. "Sibling Incest in the Royal Families of Egypt, Peru, and Hawaii." *The Journal of Sex Research* 18 (3) : 264–281. http://www.jstor.org/stable/3812218.

Bockenheimer, S. V. , Ulrich Eickhoff, Eberhard Metzel, and K. Voigt. 1978. "Radiologisch-Äquidensitographische Untersuchungen Der Kalottenverletzungen Des Pharao Seqenenre." *Fortschritte auf dem Gebiet der Röntgenstrahlen und der bildgebenden Verfahren*. 128 (6): 691–694.

Bonani, Georges, Herbert Haas, Zahi Hawass, Mark Lehner, Shawki Nakhla, John S. Nolan, Robert Wenke, and Willy Wölfli. 2001. "Radiocarbon Dates of Old and Middle Kingdom Monuments in Egypt." *Radiocarbon* 43 (3): 1297–1320. https://www.academia.edu/4222263/RADIOCARBON_DATES_OF_OLD_AND_MIDDLE_KINGDOM_MONUMENTS_IN_EGYPT.

Borchardt, Ludwig. 1899. "Der Zweite Papyrusfund von Kahun Und Die Zeitliche Festlegung Des Mittleren Reiches Der Ägyptischen Geschichte." *ZÄS* 37: 89–103.

Bronk Ramsey, Christopher, Elizabeth M. Scott, and Hans van der Plicht. 2013. "Calibration for Archaeological and Environmental Terrestrial Samples in the Time Range 26-50 Ka Cal BP." *Radiocarbon* 55 (4): 2021–2027. http://www.rug.nl/research/portal/files/2341905/2013RadiocarbonBronkRamsey.pdf.

Bronk Ramsey, Christopher, Michael W. Dee, Joanne M. Rowland, Thomas F. G. Higham, Stephen A. Harris, Fiona Brock, Anita Quiles, Eva M. Wild, Ezra S. Marcus, and Andrew J. Shortland. 2010. "Radiocarbon-Based Chronology for Dynastic Egypt." *Science* 328 (5985): 1554–1557. doi:10.1126/science.1189395.

Brugsch, Emil, and Gaston Maspero. 1881. *La Trouvaille de Deir-El-Bahari.* Le Caire: Imprimerie Française F. Mourés & Co.

Buckley, Stephen A. 2014. "Personal communication on the Mummification Techniques Applied in the Amarna Period (Turin. Museo Egizio)."

Buckley, Stephen A., Katherine A. Clark, and Richard P. Evershed. 2004. "Complex Organic Chemical Balms of Pharaonic Animal Mummies." *Nature* 431 (7006): 294–299. doi:10.1038/nature02849.

Buckley, Stephen A., and Richard P. Evershed. 2001. "Organic Chemistry of Embalming Agents in Pharaonic and Graeco-Roman Mummies." *Nature* 413 (6858): 837–841. doi:10.1038/35101588.

Buckley, Stephen A., and Arie Nissenbaum. 2013. "Dead Sea Asphalt in Ancient Egyptian Mummies-Why?" *Archaeometry* 55 (3): 563–568. doi:10.1111/j.1475-4754.2012.00713.x.

Buckley, Stephen A., Andy W. Stott, and Richard P. Evershed. 1999. "Studies of Organic Residues from Ancient Egyptian Mummies Using High Temperature-Gas Chromatography-Mass Spectrometry and Sequential Thermal Desorption-Gas Chromatography-Mass Spectrometry and Pyrolysis-Gas Chromatography-Mass Spectrometry." *Analyst* 124 (4): 443–452.

Buikstra, Jane E. 1977. "Biocultural Dimensions of Archaeological Study: A Regional Perspective." In *Biocultural Adaptation in Prehistoric America. Proceedings of the Southern Anthropological Society 11*, edited by R.L. Blakely, 67–84. Athens (USA): University of Georgia.

Buikstra, Jane E., and Douglas H. Ubelaker 1994. *Standards for Data Collection from Human Skeletal Remains.* Fayetteville: Arkansas Archeological Survey.

Camerarius, Philipp, and Georg Maier. 1625. *Philippi Camerarii Operae Horarum Succisivarum, Sive, Meditationes Historicae, Das Ist, Historischer Lustgarten : In Welchemallerley Denckwirdige, Nützliche Vnd Lustige Historien Und Exempel Zu Finden : Secunda Centuria Historica : Das Ist, Ander Theil De*. Leipzig: Leipzig : In Verlegung Michael Wachssmanns Buchh.

Campana, Michael G., Nelly Robles García, Frank J. Rühli, and Noreen Tuross. 2014. "False Positives Complicate Ancient Pathogen Identifications Using High-Throughput Shotgun Sequencing." *BMC Research Notes* 7 (January): 111. doi:10.1186/1756-0500-7-111.

Clarke, Emily M., Randall C. Thompson, Adel H. Allam, L. Samuel Wann, Guido P. Lombardi, M. Linda Sutherland, James D. Sutherland, et al. 2014. "Is Atherosclerosis Fundamental to Human Aging? Lessons from Ancient Mummies." *Journal of Cardiology* 63 (5): 329–334. doi:10.1016/j.jjcc.2013.12.012.

Colombini, Maria Perla, Francesca Modugno, F. Silvano, and M. Onor. 2000. "Characterization of the Balm of an Egyptian Mummy from the Seventh Century B.C." *Studies in Conservation* 45 (1): 19–29.

Conan Doyle, Arthur. 1922. "Lot No. 249." In *Tales of Twilight and the Unseen*. John Murray. https://www.arthur-conan-doyle.com/index.php/Tales_of_Twilight_and_the_Unseen.

David, Rosalie Ann. 1979. *The Manchester Museum Mummy Project : Multidisciplinary Research on Ancient Egyptian Mummified Remains*. Manchester: Manchester University Press.

Davis, Theodore M. 1910. *The Tomb of Queen Tiyi.* London: Constable & Co.

Dawson, Warren R., and P. H. K. Gray. 1968. *Catalogue of Egyptian Antiquities in the British Museum I: Mummies and Human Remains.* London: British Museum Studies in Ancient Egypt and Sudan (BMSAES).

Dee, Michael W., Christopher Bronk Ramsey, Andrew J. Shortland, Thomas F G Higham, and Joanne M. Rowland. 2009. "Reanalysis of the Chronological Discrepancies Obtained by the Old and Middle Kingdom Monuments Project." *Radiocarbon* 51 (3): 1061–1070.

Delorenzi, Enzo, and Renato Grilletto. 1989. *Le Mummie Del Museo Egizio Di Turino N 13001-13026. Indagine Anthropo-Radiologica.* Milano: Istituto Ed. Cisalpino - La Goliardica.

Der Manuelian, Peter, and Thomas Schneider, Eds. 2015. *Towards a New History for the Egyptian Old Kingdom. Perspectives on the Pyramid Age*. . Leiden: Brill.

Derry, Douglas E. 1927 (2010 edition). "Report Upon The Examination Of Tut-Ankh-Amen's Mummy." In *The Tomb of Tut.Ankh.Amen. Vol 2*, edited by Howard Carter, 143–161. Cambridge: Cambridge University Press.

Derry, Douglas E. 1931. "Note On The Skeleton Hitherto Believed To Be That Of King Akhenaten." *Annales du Service des Antiquités de l'Égypte* 31: 115–119.

Derry, Douglas E. 1939. "An X-Ray Examination Of The Mummy Of King Amenophis I." *Annales du Service des Antiquités de l'Égypte* 34: 47–48.

Derry, Douglas E. 1940. "An Examination Of The Bones Of King Psusennes I." *Annales du Service des Antiquités de l'Égypte* 40: 967–940.

Derry, Douglas E. 1942. "Mummification II - Methods Practiced at Different Periods." *Annales du Service des Antiquités de l'Égypte* 41: 240–265.

Diodorus. "Diodorus Siculus. The Library of History." http://penelope.uchicago.edu/Thayer/E/Roman/Texts/Diodorus_Siculus/home.html.

Duggan, Ana T., Maria F. Perdomo, Dario Piombino-Mascali, Stephanie Marciniak, Debi Poinar, Matthew V. Emery, Jan P. Buchmann, et al. 2016. "17th Century Variola Virus Reveals the Recent History of Smallpox." *Current Biology* 26 (24): 3407–3412. doi:http://dx.doi.org/10.1016/j.cub.2016.10.061.

Duhig, Corinne. 2010. "The Remains of Pharaoh Akhenaten Are Not yet Identified: Comments on 'Biological Age of the Skeletonised Mummy from Tomb KV55 at Thebes (Egypt)' by Eugen Strouhal in Anthropologie." *International Journal of the Science of Man* 48 (2): 113.-115.

Dunham, Dows, and William K. Simpson. 1974. *The Mastaba of Queen Mersyankh III. G 7530-7540*. Boston: Museum of Fine Arts.

Eaton-Krauss, Marianne. 2002. "Akhenaten Redux." *Chronique d'Égypte* 77: 93–107.

El-Aref, Nevine. 2015. "INTERVIEW: Nicholas Reeves '60% Sure' Ahead of Nefertiti Announcement." *Ahram Online*. http://english.ahram.org.eg/News/151753.aspx.

Felix, Joseph. 1965. *Herodot. Historien, Griechisch-Deutsche Übersetzung*. München: Heimeran Verlag.

Finch, Caleb E. 2011. "Atherosclerosis Is an Old Disease: Summary of the Ruffer Centenary Symposium, The Paleocardiology of Ancient Egypt, a Meeting Report of the Horus Study Team." *Experimental Gerontology* 46 (11): 843–846. doi:10.1016/j.exger.2011.08.011.

Fleming, Stuart, Bernard Fishman, David B. O'Connor, and David Silverman. 1980. *The Egyptian Mummy Secrets and Science*. Philadelphia: The University of Pennsylvania.

Fletcher, Joann. 2004. *The Search for Nefertiti*. London: Hodder and Stroughton.

Fletcher, Joann. 2015. *The Story of Egypt*. London: Hodder and Stroughton.

Fornaciari, Antonio, Valentina Giuffra, Emanuelle Armocida, Davide Caramella, Frank J. Rühli, and Francesco M. Galassi. 2018. "Paleopathology of Gout: Insights from the Notable Case of Duke Federico Da Montefeltro (1422-1482)." *Clinical and Experimental Rheumatology* 36: 15–20. http://www.clinexprheumatol.org/article.asp?a=11700.

Fornaciari, Gino. 1999. "Renaissance Mummies in Italy." *Medicina Nei Secoli* 11 (1): 85–105. http://www.ncbi.nlm.nih.gov/pubmed/11624203.

Fornaciari, Gino, and Raffaele Gaeta. 2013. "Atherosclerosis in Ancient Populations." *Lancet* 382 (9887): 123. doi:10.1016/S0140-6736(13)61554-8.

Frandsen, Paul J. 2009. *Incestuous and Close-Kin Marriage in Ancient Egypt and Persia: An Examination of the Evidence*. Copenhagen: Museum Tusculanum Press. http://www.degruyter.com/view/j/zrgra.2012.129.issue-1/zrgra.2012.129.1.665/zrgra.2012.129.1.665.xml.

Frayling, Christopher. 1996. *Geschichten Um Tutanchamun*. London: British Broadcasting Corporation [Documentary movie, German version]

Frayling, Christopher, Roy Davies, and Derek Towers. 1992. *The Face of Tutankhamun*. London: Faber and Faber.

Friedrich, Walter L. 2013. "The Minoan Eruption of Santorini around 1613 B. C. and Its Consequences." In *Tagungen Des Landesmuseums Für Vorgeschichte Halle, Band 9*, edited by François Beremes Harald Meller and Roberto Risch Hans-Rudolf Bork, 37–48. Langenweißbach: Beier & Beran. http://geo.au.dk/fileadmin/www.geo.au.dk/02_Forskning/Publikationer/friedrich_satz.pdf.

Friedrich, Walter L., Bernd Kromer, Michael Friedrich, Jan Heinemeier, Tom Pfeiffer, and Sahra Talamo. 2006. "Santorini Eruption Radiocarbon Dated to 1627-1600 B.C." *Science* 312: 548. doi:10.1126/science.1125087.

Gabolde, Marc. 1998. *D'Akhenaton à Toutânkhamon*. Paris: De Boccard.

Gabolde, Marc. 2013. "L'ADN de La Famille Royale Amarnienne et Les Source Égyptiennes." *Egypte Nilotique et Méditeranéenne ENiM* 6: 177–203. http://www.enim-

egyptologie.fr/revue/2013/10/Gabolde_ENIM6_p177-203.pdf.

Gad, Yehia Z. 2010. “King Tutankhamun’s Family and Demise (Reply).” *JAMA : The Journal of the American Medical Association* 303 (24): 2473–2475.

Gaeta, Raffaele, Valentina Giuffra, and Gino Fornaciari. 2013. “Atherosclerosis in the Renaissance Elite: Ferdinand I King of Naples (1431-1494).” *Virchows Archiv : An International Journal of Pathology* 462 (5): 593–595. doi:10.1007/s00428-013-1400-x.

Galanopoulos, Angelos George, and Edward Bacon. 1978. *Die Wahrheit Über Atlantis*. München: Heyne.

Galassi, Francesco M., Michael E. Habicht, Abigail S. Bouwman, and Frank J. Rühli. 2018. “The Canopic Jar Project: Interdisciplinary Analysis of Ancient Mummified Viscera.” *CIPEG*. URN: http://nbn-resolving.de/urn:nbn:de:bsz:16-cipeg-441655

Galassi, Francesco M., Michael E. Habicht, and Frank J. Rühli. 2016. “Poliomyelitis in Ancient Egypt?” *Neurological Sciences* 38 (2): 375. doi:10.1007/s10072-016-2720-9.

Galassi, Francesco M., Michael E. Habicht, Frank J. Rühli, and Stefano De Carolis. 2017. “A Unique Case of Stroke and Upper Limb Paralysis in a Mid-18th Century Natural Mummy.” *Circulation Research* 121 (4): 338–340. doi:10.1161/CIRCRESAHA.117.311427.

Galassi, Francesco M., Maciej Henneberg, Wouter De Herder, Frank J. Rühli, and Michael E. Habicht. 2017. “Oldest Case of Gigantism? Assessment of the Alleged Remains of Sa-Nakht, King of Ancient Egypt.” *Lancet Diabetes & Endocrinology* 5 (8): 580–581. doi:http://dx.doi.org/10.1016/S2213-8587(17)30171-7 showArticle Info.

Gardiner, Alan H. 1945. “Regal Years and Civil Calendar in Pharaonic Egypt.” *Journal of Egyptian Archaeology* 31: 11–28.

Gardiner, Alan H. 1959. *The Royal Canon of Turin*. Oxford: Oxford University Press.

Garstang, John. 1903. *Maḥâsna and Bêt Khallâf*. London: Quaritch. http://digi.ub.uni-heidelberg.de/diglit/garstang1903/0018.

Gates, Josh. 2018. *February 5th, 2018 Get an Exclusive First Look at the Face of King Tut’s Mother, Queen Nefertiti*. https://www.today.com/video/get-an-exclusive-first-look-at-the-face-of-king-tut-s-mother-queen-nefertiti-1153878083619.

Gautschy, Rita. 2011. “Die Monddaten Aus Dem Archiv von Illahun: Chronologie Des Mittleren Reiches.” *Zeitschrift für Ägyptische Sprache* 138: 1–19.

Gautschy, Rita, Michael E. Habicht, Francesco M. Galassi, Daniela Rutica, Rainer Hannig, and Frank J. Rühli. 2017. “A New Astronomically Based Chronological Model for the Egyptian Old Kingdom.” *Journal of Egyptian History* 10 (2): 69–108. doi:10.1163/18741665-12340035.

Germer, Renate. 1994. *Das Geheimnis Der Mumien*. Reinbeck: Rowohlt Tb.

Grilletto, R. 1991. *Materiali Antropologici e Zoologici Provenienti Dall’Egitto e Conservati Nel Museo Egizio Di Torino e Nel Museo Di Anthropologia Dell’ Università Di Torino, Consistenza e Collocazione Al 1991*. Torino.

Grimal, Nicolas. 1992. *Histoire de l’Egypte Ancienne*. Paris: Arthème Fayard.

Habicht, Michael E. 2011. *Nofretete Und Echnaton: Das Geheimnis Der Amarna-Mumien*. Leipzig: Koehler + Amelang Gmbh.

Habicht, Michael E., Raffaella Bianucci, Stephen A. Buckley, Joann Fletcher, Abigail S. Bouwman,

Lena M. Öhrström, Roger Seiler, et al. 2016. “Queen Nefertari, the Royal Spouse of Pharaoh Ramses II: A Multidisciplinary Investigation of the Mummified Remains Found in Her Tomb (QV66).” *PloS One* 11 (11): e0166571. doi:10.1371/journal.pone.0166571.

Habicht, Michael E., Abigail S. Bouwman, and Frank J. Rühli. 2016. “Identifications of Ancient Egyptian Royal Mummies from the 18th Dynasty Reconsidered.” *American Journal of Physical Anthropology* 159 (Suppl 61): S216-31. doi:10.1002/ajpa.22909.

Habicht, Michael E., Patrick E. Eppenberger, Francesco M. Galassi, Frank J. Rühli, and Maciej Henneberg. 2018. “Queen Meresankh III – the Oldest Case of Bilateral Silent Sinus Syndrome (c. 2630/20 - 2587 BC)?” *Anthropologie* 56 (1). doi:10.26720/anthro.17.09.25.2.

Habicht, Michael E., Francesco M. Galassi, Wolfgang Wettengel, and Frank J. Rühli. 2015. “Who Else Might Be in Pharaoh Tutankhamun’s Tomb (KV 62, c. 1325 BC)? [Online].” *Academia*. doi:10.13140/RG.2.1.4408.1361.

Habicht, Michael E., Maciej Henneberg, Lena M. Öhrström, Kaspar Staub, and Frank J. Rühli. 2015. “Body Height of Mummified Pharaohs Supports Historical Suggestions of Sibling Marriages.” *American Journal of Physical Anthropology* 157 (3): 519–525. doi:10.1002/ajpa.22728.

Habicht, Michael E., Renate Siegmann, Rita Gautschy, Daniela Rutica, and Rainer Hannig. 2015. “A New Sothis Rise on a Small Cylindrical Jar from the Old Kingdom.” *Göttinger Miszellen* 247: 41–50. https://www.academia.edu/7967184/A_New_Sothis_Rise_on_a_Small_Cylindrical_Jar_from_the_Old_Kingdom_2015_.

Hajdas, Irka, Carlos Cristi, Georges Bonani, and Mantana Maurer. 2014. “Textiles and Radiocarbon Dating.” *Radiocarbon* 56: 637–643.

Hammer, Claus U., Henrik B. Clausen, Walter L. Friedrich, and Henrik Tauber. 1987. “The Minoan Eruption of Santorini in Greece Dated to 1645 BC?” *Nature* 328 (6): 517–519. http://www.nature.com/nature/journal/v328/n6130/abs/328517a0.html.

Hannig, Rainer. 2009. *Grosses Handwörterbuch Ägyptisch-Deutsch: (2800-950 v. Chr.)*. Mainz: von Zabern.

Harrell, James A., and Michael D. Lewan. 2002. “Sources of Mummy Bitumen in Ancient Egypt and Palestine.” *Archaeometry* 44 (2): 285–293.

Harris, James E., and Kent R. Weeks. 1973. *X-Raying the Pharaohs*. New York: Charles Sccibner’s Sons.

Harris, Mark. 2013. *Mark Harris - The Thera Theories: Science and the Modern Reception History of the Exodus*. https://www.youtube.com/watch?v=BGsdkIVTrOo.

Harrison, Reginald G. 1966. “An Anatomical Examination Of The Pharaonic Remains Purported To Be Akhenaton.” *Journal of Egyptian Archaeology* 52: 95–119.

Harrison, Reginald G., and A. B. Abdalla. 1972. “The Remains of Tutankhamun.” *Antiquity* 46: 8–14.

Hawass, Zahi, Yehia Z. Gad, Somaia Ismail, Rabab Khairat, Dina Fathalla, Naglaa Hasan, Amal Ahmed, et al. 2010. “Ancestry and Pathology in King Tutankhamun’s Family.” *JAMA : The Journal of the American Medical Association* 303 (7): 638–647. doi:10.1001/jama.2010.121.

Hawass, Zahi, and Sahar N. Saleem. 2016. *Scanning the Pharaohs. CT Imaging of the New Kingdom Royal Mummies*. Cairo: American University of Cairo Press.

Hawass, Zahi, M. Shafik, Frank Rühli, and Ashraf Selim. 2007. “Computed Tomographic Evaluation

of Pharaoh Tutankhamun, ca. 1300 BC." *Annales du Service des Antiquités de l'Égypte* 81: 159–173.

Helck, Wolfgang. 1987. *Untersuchungen Zur Thinitenzeit*. Wiesbaden: Otto Harrassowitz.

Hermanussen, Michael, Christoph Alt, Kaspar Staub, Christian Assmann, and Detlef Groth. 2014. "The Impact of Physical Connectedness on Body Height in Swiss Conscripts." *Anthropologischer Anzeiger* 71 (4): 313–327. doi:10.1127/0003-5548/2014/0466.

Hornung, Erik, Rolf Krauss, and David A. Warburton, Eds. 2006. *Ancient Egyptian Chronology*. Leiden: Brill.

Incordino, Illaria. 2007. "The Third Dynasty: A Historical Hypothesis." In *Proceedings of the Ninth International Congress of Egyptologists*, edited by Jean-Claude Goyon, 965. Leuven: Peeters Publishers.

Incordino, Illaria. 2008. "Reign of Horus Sanakht: Possible Founder of the Third Dynasty." In *Recent Discoveries and Latest Researches in Egyptology. Proceedings of the First Neapolitan Congress of Egyptology, Naples, June 18th-20th 2008*, edited by Francesco Raffaele, Massimiliano Nuzzolo and Ilaria Incordino, 145-155. Wiesbaden: Harrassowitz. https://www.academia.edu/1215148/Reign_of_Horus_Sanakht_possible_founder_of_the_Third_Dynasty_in_Recent_Discoveries_and_latest_researches_in_Egyptology._Proceedings_of_the_First_Neapolitan_Congress_of_Egyptology_Naples_June_18th-20th_2008._Edited_by_Franc.

Jones, Ashley 2001. "Incest in Ancient Egypt." Unpublished manuscript. http://cnersundergraduatejournal.files.wordpress.com/2011/06/incest_in_ancient_egypt_revised_.pdf.

Kanz, Fabian, Karl Grossschmidt, and Jan Cemper-Kiesslich. 2009. "Arsinoe IV of Egypt, Sister of Cleopatra Identiried? Osseous and Molecular Challenges." *American Journal of Physical Anthropology* 138(S48): 162. https://www.researchgate.net/publication/289536107_Arsinoe_IV_of_Egypt_sister_of_Cleopatra_identiried_Osseous_and_molecular_challenges.

Koenig, Walter. 1896. *14 Photographien von Röntgenstrahlen Aufgenommen Im Physikalischen Verein Zu Frankfurt a. M.* Leipzig: M. Johann Ambrosius Barth.

Krauss, Rolf. 2009. "Der Berliner 'Spaziergang Im Garten' - Antiker Murks Oder Moderne Fälschung?" *Palarch's Journal of Archaeology of Egypt/Egyptology* 6 (1): 1–20. http://www.palarch.nl/wp-content/egt_2009_6_12.pdf.

Kutschera, Walter, Manfred Bietak, Eva M. Wild, Franz Weninger, Michael Dee, Robin Golser, Christopher Bronk Ramsey, et al. 2013. "The Chronology of Tell El-Daba: A Crucial Meeting Point of 14C Dating, Archaeology, and Egyptology in the 2nd Millennium BC." *Radiocarbon* 54 (3–4): 407–422. doi:10.1017/S0033822200047172.

Larsen, Clark Spencer. 1987. "Bioarchaeological Interpretations of Subsistence Economy and Behavior from Human Skeletal Remains." *Advances in Archaeological Method and Theory* 10: 339–445.

Larsen, Clark Spencer. 1997. *Bioarchaeology: Interpreting Behavior from the Human Skeleton.* Cambridge: Cambridge University Press.

Leca, Ange-Pierre. 1986. *La Medicina Egizia : Al Tempo Dei Faraoni*. Ciba-Geigy. Turin: Ciba-Geigy Edizioni.

Leek, Filce F. 1972. "*The Human Remains from the Tomb of Tut'ankhamun*." . Oxford: Griffith

Institute.

Loges, Luise. 2014. “Die Vergessene Dynastie.” In *Das Reich Der Ägypter*, edited by Spektrum der Wissenschaft, 87–89. Heidelberg.

Lorenzen, Eline D, and Eske Willerslev. 2010. “King Tutankhamun’s Family and Demise.” *JAMA : The Journal of the American Medical Association* 303 (24): 2471; author reply 2473-5. doi:10.1001/jama.2010.818.

Lorenzi, Rossella. 2015. “Who Else May Be in King Tut’s Tomb?” *Discovery News*. http://news.discovery.com/history/archaeology/who-else-may-be-in-king-tuts-tomb-151015.htm.

Macaulay, George C. 1890. “Herodot, II.” http://www.sacred-texts.com/cla/hh/index.htm#section_001.

Malek, Jaromir. 1982. “The Original Version of the Royal Canon of Turin.” *Journal of Egyptian Archaeology* 68: 93–106.

Malmström, Helena, Jan Storå, Love Dalén, Gunilla Holmlund, and Anders Götherström. 2005. “Extensive Human DNA Contamination in Extracts from Ancient Dog Bones and Teeth.” *Molecular Biology and Evolution* 22 (10): 2040–2047. doi:10.1093/molbev/msi195.

Manning, Stuart. 2014. “Ancient Egyptian Tree Rings Support Chronology.” *Archaeology* 15 May 2014. http://www.archaeology.org/news/2112-140515-egypt-dendrochronology-climate.

Manning, Stuart W., Cemal Pulak, Bernd Kromer, S. Talamo, Christopher Bronk Ramsey, and Michael W Dee. 2009. “Absolute Age of the Uluburun Shipwreck: A Key Late Bronze Age Time-Capsule for the East Mediterranean.” In *Tree-Rings, Kings and Old World Archaeology and Environment*, edited by Stuart W. Manning and M. J. Bruce, 163–187. Oxford: Oxbow. http://www.jstor.org/stable/j.ctt1cfr7x1.

Martin, Rudolf, and Karl Saller. 1957. *Lehrbuch Der Anthropologie in Systematischer Darstellung*. Stuttgart: Fischer.

Martina, Maria C., Federico Cesarani, Rosa Boano, Anna M. Donadoni Roveri, Andrea Ferraris, Renato Grilletto, and Giovanni Gandini. 2005. “Kha and Merit: Multidetector Computed Tomography and 3D Reconstructions of Two Mummies from the Egyptian Museum of Turin.” *Journal of Biological Research* 80(1): 42–44.

Müller-Römer, Frank. 2015. “Kritische Anmerkung Zu ‘The Burial of Nefertiti?’ Von Nicholas Reeves.” Unpublished manuscript. https://www.academia.edu/14921317/Kritische_Anmerkung_zu_The_Burial_of_Nefertiti_von_Nicholas_Reeves.

Murray, Margaret A. 1910. *The Tomb of Two Brothers*. Manchester: Sheerrat & Co.

Myers, Charles S. 1901. “The Bones of Hen Nekht, an Egyptian King of the Thrid Dynasty.” *Man* 1: 152–153. http://www.jstor.org/stable/2839307.

Nerlich, Andreas G, Stephen A. Buckley, Joann Fletcher, Sara Caramello, and Raffaella Bianucci. 2014. “An Interdiscipilary Study of the Mummified Remains of the 18th Dynasty Official Nebiri (P).” In *The Bioarchaeology of Ancient Egypt Abstracts 2013*, edited by Salima Ikram. *PalArch’s Journal of Archaeology of Egypt/Egyptology* 10(1): 22.

Nolan, John S. 2003. “The Original Lunar Calendar and Cattle Counts in Old Kingdom Egypt.” *Aegyptiaca Helvetica* 17: 75–97.

Nolan, John S. 2008. “Lunar Intercalations and ‘Cattle Counts’ during the Old Kingdom: The Hebsed

Context." In *Chronology and Archaeology in Ancient Egypt (the Third Millennium B.C.)*, edited by Hana Vymazalová, 42–60. Prague: Czech Institute of Egyptology, Faculty of Arts, Charles University.

Nolan, John S. 2015. "Cattle, Kings and Priests: Phyle Rotation and Old Kingdom Civil Dates." In *Towards a New History for the Egyptian Old Kingdom. Perspectives on the Pyramid Age*, edited by Peter Der Manuelian and Thomas Schneider, 337–365. Leiden: Brill.

Owen, Timothy D. 2000. "Bone Sampling for Isotope Analysis." *Australian Archaeology* 54: 57–58.

Pääbo, Svante. 1985. "Molecular Cloning of Ancient Egyptian Mummy DNA." *Nature* 314 (6012): 644–645. http://www.ncbi.nlm.nih.gov/pubmed/3990798.

Partridge, Robert. 1994. *Faces of Pharaohs: Royal Mummies and Coffins from Ancient Thebes*. London: Rubicon Press.

Pate, F. Donald. 1994. "Bone Chemistry and Paleodiet." *Journal of Archaeological Method and Theory* 1 (2): 161–209. https://link.springer.com/content/pdf/10.1007%2FBF02231415.pdf.

Pate, F. Donald. 2008. "Geographic Origin and Mobility Recorded in the Chemical Composition of Human Tissues." In *Forensic Approaches to Death, Disaster and Abuse*, edited by M Oxenham, 177–188. Brisbaine: Brisbaine Academic Press.

Pettigrew, Thomas Joseph. 1834. *A History of Egyptian Mummies, and an Account of the Worship and Embalming of the Sacred Animals by Egyptians.* London: Orme, Brown, Green, and Longman.

Piacentini, Patrizia, and Christian Orsenigo. 2004. *La Valle Dei Re Riscoperta. I Giornali Di Scavo Di Victor Loret (1898-1899) e Altri Inediti (Le Vetrine Del Sapere 1)*. Milano: Università degli Studi di Milano.

Pierce, Charles A. 1996. "Body Height and Romantic Attraction: A Meta-Analytic Test Of The Male-Taller Norm." *Social Behavior and Personality: An International Journal* 24 (2): 143–149. doi:10.2224/sbp.1996.24.2.143.

Quiles, Anita, Eric Aubourg, B. Berthier, Emmanuelle Delqué-Kolic, Genevieve Pierrat-Bonnefois, Michael W. Dee, Guillemette Audreu-Lanoe, Christopher Bronk Ramsey, and Christophe Moreau. 2012. "Bayesian Modelling of an Absolute Chronology for Egypt's 18th Dynasty by Astrophysical and Radiocarbon Methods." *Journal of Archaeological Science* 40: 423–432. https://halshs.archives-ouvertes.fr/in2p3-00742997/document.

Raven, Maarten J., and Wybren K. Taconis. 2005. *Egyptian Mummies. Radiological Atlas of the Collections in the National Museum of Antiquities in Leiden*. Brepols: Turnhout.

Reeves, Nicholas C. 2015. "The Burial of Nefertiti?" *Amarna Royal Tombs Project. Occasional Papers* 1: 1–16. https://www.academia.edu/14406398/The_Burial_of_Nefertiti_2015_.

Reimer, Paul J., Edouard Bard, Alex Bayliss, J. Warren Beck, Paul G. Blackwell, Christopher Bronk Ramsey, Caitlin E. Buck, et al. 2013. "IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0-50,000 Years Cal BP." *Radiocarbon* 55 (4): 1869-1887.

Robins, Gay, and Charles C. D. Shute. 1986. "Predynastic Egyptian Stature and Physical Proportions." *Human Evolution* 1(4) 313-324. doi:10.1007/BF02436705.

Robins, Gay, and Charles C.D. Shute. 1983. "The Physical Proportions and Living Stature of New Kingdom Pharaohs." *Journal of Human Evolution* 12 (5): 455–465. doi:10.1016/S0047-2484(83)80141-9.

Ruffer, Marc Armand. 1910. "Note On The Presence Of Bilharzia Haematobia In Egyptian Mummies

Of The Twentieth Dynasty." *The British Medical Journal* 1: 16.

Ruffer, Marc Armand, and Roy Lee Moodie. 1921. *Studies in the Palaeopathology of Egypt*. Chicago: The University of Chicago Press.

Rühli, Frank J., Francesco M. Galassi and Martin Häusler. 2016. "Palaeopathology: Current Challenges and Medical Impact." *Clinical Anatomy* 29 (7): 816–822. doi:10.1002/ca.22709.

Rühli, Frank J., Michael E. Habicht, Stephen A. Buckley, Lena M. Öhrström, Roger Seiler, Thomas Böni, and Raffaella Bianucci. 2017. 'Evidence' in Identifying Royal and Non-Royal Mummies: General Considerations and a Specific Example (Mummified Remains from QV 66; Queen Nefertari) In Proceedings of the XI *International Congress of Egyptologists, Florence, Italy 23-30 August 2015,* edited by M. Cristina Guidotti and Gloria Rosati. Oxford: Archaeopress Archaeology.

Rühli, Frank J. and Salima Ikram. 2014. "Purported Medical Diagnoses of Pharaoh Tutankhamun, c. 1325 BC." *HOMO Journal of Comparative Human Biology* 65: 51–63.

Saleem, Sahar N. and Zahi Hawass. 2015. "Subcutaneous Packing in Royal Egyptian Mummies Dated From 18th to 20th Dynasties [Online]." *Journal Computed Assisted Tomography* 39 (3): 301–306. doi:10.1097/RCT.0000000000000205.

Scheidel, Walter. 1996. "Brother-Sister and Parent-Child Marriage Outside Royal Families in Ancient Egypt and Iran: A Challenge to the Sociobiological View of Incest Avoidance?" *Ethology and Sociobiology*. doi:10.1016/S0162-3095(96)00074-X.

Schlögl, Hermann A. 2012. *Nofretete. Die Wahrheit Über Die Schöne Königin*. München: Beck C. H.

Schneider, Thomas. 1996. *Lexikon Der Pharaonen*. München: Deutscher Taschenbuch Verlag GmbH and Co.

Schuenemann, Verena J., Alexander Peltzer, Beatrix Welte, W. Paul Van Pelt, Martyna Molak, Chuan Chao Wang, Anja Furtwängler, et al. 2017. "Ancient Egyptian Mummy Genomes Suggest an Increase of Sub-Saharan African Ancestry in Post-Roman Periods." *Nature Communications* 8: 15694 (2017). doi:10.1038/ncomms15694.

Seiler, Roger, Andrew I. Spielman, Albert Zink, and Frank J. Rühli. 2013. "Oral Pathologies of the Neolithic Iceman, c.3,300 BC." *European Journal of Oral Sciences* 121 (3 Pt 1): 137–141. doi:10.1111/eos.12037.

Shattock, Samuel G. 1909. "A Report upon the Pathological Condition of the Aorta of King Menephtah, Traditionally Regarded as the Pharaoh of the Exodus." *Proceedings of the Royal Society of Medicine* 2: 122–127.

Shortland, Andrew J., Christopher Bronk Ramsey, Michael Dee, and Fiona Bronk. 2013. *Radiocarbon and the Chronologies of Ancient Egypt*. Oxford; Oaksville: Oxbow Books.

Smith, G. Elliot. 1912. *The Royal Mummies*. Cairo: Impr. de l'Inst. Français d'Archéolgie Orientale London: Duckworth (reprint 2000).

Soparkar, Charles N., James R. Patrinely, and M. Janet Cuaycong. 1994. "The Silent Sinus Syndrome. A Cause of Spontaneous Enophthalmos." *Ophthalomolgy* 101: 772–778.

Stoker, Bram. 1903. *The Jewel of Seven Stars*. http://www.bramstoker.org/novels/08stars.html.

Strouhal, Eugen. 1982. "Queen Mutnodjmet at Memphis: Anthropological and Paleopathological Evidence." In *L'Egyptologie En 1979 Vol. 2*, edited by Jean Leclant, 317–322. Paris: Editions du CNRS.

Strouhal, Eugen. 1984. “Princess Khekeretnebty and Tisethor: Anthropological Analysis.” *Anthropologie* 22: 171–182.

Strouhal, Eugen. 1992. “Anthropological and Archaeological Identification of an Ancient Egyptian Royal Family (5th Dynasty).” *International Journal of Anthropology* 7 (3): 43–63.

Strouhal, Eugen, and Luboš Vyhnánek. 1980. *Egyptian Mummies in Czechoslovak Collections*. Prague: Národní Muzeum.

Strouhal, Eugen, and Luboš Vyhnánek. 2000. “The Identification of the Remains of King Neferefra.” In *Abusir and Saqqara in the Year 2000*, edited by Miroslav Barta, 551–560. Prague: Academy of Sciences of the Czech Republic- Oriental Institute.

ten Berge, Rosita L., and Frank R.W. van de Goot. 2002. “Seqenenre Taa II, the Violent Death of a Pharaoh.” *Journal of Clinical Pathology* 55 (3): 232. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1769615&tool=pmcentrez&rendertype=abstract.

Thews, Jolly. 2018. “Gesicht Der „Younger Lady“ Rekonstruiert.” *Selkets Blog*. https://blog.selket.de/aus-der-forschung/gesicht-der-younger-lady-rekonstruiert.

Thompson, Randall C., Adel H. Allam, Guido P. Lombardi, L. Samuel Wann, M. Linda Sutherland, James D. Sutherland, Muhammad Al-Tohamy Soliman, et al. 2013. “Atherosclerosis across 4000 Years of Human History: The Horus Study of Four Ancient Populations.” *Lancet* 381 (9873): 1211–1222. doi:10.1016/S0140-6736(13)60598-X.

Timmann, Christian, and Christian G. Meyer. 2010. “King Tutankhamun’s Family and Demise.” *JAMA : The Journal of the American Medical Association* 303 (24): 2473; author reply 2473-5. doi:10.1001/jama.2010.822.

Verner, Miroslav, Vivienne G. Callender, and Eugen Strouhal. 2002. *Abusir VI. Djedkare’s Family Cemetry*. Prague: Czech Institute of Egyptology.

von Beckerath, Jürgen. 1997. *Chronologie Des Pharaonischen Ägypten*. Mainz: Philipp von Zabern.

von Beckerath, Jürgen. 1999. *Handbuch Der Altägyptischen Königsnamen*. Mainz: Philipp von Zabern.

Wasef, Sally, Rachel Wood, Samia El Merghani, Salima Ikram, Caitlin Curtis, Barbara Holland, Eske Willerslev, Craig D. Millar, and David Martin Lambert. 2015. “Radiocarbon Dating of Sacred Ibis Mummies from Ancient Egypt.” *Journal of Archaeological Science* 4: 355–361. doi:10.1016/j.jasrep.2015.09.020.

Weeks, Kent R. 1999. *Ramses II: Das Totenhaus Der Söhne*. New York: William Morrow.

Wegner, Joseph. 2014a. “Press Release: Giant Sarcophagus Leads Penn Museum Team in Egypt to the Tomb of a Previousely Unknown Pharaoh.” University of Pennsylvania Museum of Archaeology and Anthropology. http://www.penn.museum/press-releases/1032-pharaoh-senebkay-discovery-josef-wegner.html.

Wegner, Joseph. 2014b. “Kings of Abydos, Solving an Ancient Egyptian Mystery.” *Current World Archaeology* 64: 18–25. http://www.world-archaeology.com/issue-64/cwa-64.htm.

Wilkinson, Toby A.H. 2001. *Early Dynastic Egypt*. London: Routledge.

Willeitner, Joachim, and Heike C. Schmidt. 1997. *Nefertari. Gemahlin Ramses II.* Mainz: Philipp Von Zabern.

Wortman, Matthew. 2003. *Nefertiti: Resurrected*. London: Atlantic Productions.[Doucmentary movie] http://www.imdb.com/title/tt0378431/?ref_=fn_al_tt_4.

Zakrzewski, Sonia R. 2003. "Variation in Ancient Egyptian Stature and Body Proportions." *American Journal of Physical Anthropology* 121 (3): 219–229.

Appendix

The appendix lists all publications including their appendices in original layout as published in various scientific journals.

American Journal of PHYSICAL ANTHROPOLOGY
The Official Journal of the American Association of Physical Anthropologists

Brief Communication

Body height of mummified pharaohs supports historical suggestions of sibling marriages

Michael E. Habicht
Maciej Henneberg
Lena M. Öhrström
Kaspar Staub
Frank J. Rühli

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Abstract

Body height is an important factor in reconstructing health conditions and it serves as an indicator of socio-economic status. Researchers rely on ancient data to analyze evolutionary aspects of human health and its interrelation with environmental influences. This study presents body height estimates from all periods of ancient Egyptian history and compares the general population with the existing mummies of the members of royal families. A sample of 259 adult Egyptian mummies originating from various collections and published sources with body lengths (long bone measures or/and overall measurements, CT data) were analyzed, and royal mummies were scored with respect to the level of consanguinity. Male royals were taller than males in the general ancient Egyptian population, while female royals were shorter than females in the general population. The body height variation of the royals is significantly reduced when compared with a pool of non-royal mummies. This provides evidence for inbreeding resulting from consanguineous marriages. However, there appears to be no correlation between the level of inbreeding and individual body height. The random sample of general population does not show signs of inbreeding. Due to the present lack of larger, technically and ethically challenging genetic studies, the selected non-invasive approach of body height is the most reliable indicator of sibling marriages of pharaohs based on direct physical evidence. Am J Phys Anthropol 157:519–525, 2015.

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Identifications of ancient Egyptian royal mummies from the 18th Dynasty reconsidered

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ABSTRACT

For centuries, ancient Egyptian Royal mummies have drawn the attention both of the general public and scientists. Many royal mummies from the New Kingdom have survived. The discoveries of the bodies of these ancient rulers have always sparked much attention, yet not all identifications are clear even nowadays. This study presents a meta-analysis to demonstrate the difficulties in identifying ancient Egyptian royal mummies. Various methods and pitfalls in the identification of the Pharaohs are reassessed since new scientific methods can be used, such as ancient DNA-profiling and CT-scanning. While the ancestors of Tutankhamun have been identified, some identities are still highly controversial (e.g., the mystery of the KV-55 skeleton, recently most likely identified as the genetic father of Tutankhamun). The meta-analysis confirms the suggested identity of some mummies (e.g., Amenhotep III, Thutmosis IV, and Queen Tjye). Am J Phys Anthropol 159:S216–S231, 2016. © 2016 American Association of Physical Anthropologists

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RESEARCH ARTICLE

Shedding New Light on the 18th Dynasty Mummies of the Royal Architect Kha and His Spouse Merit

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Abstract

The mummies of Kha and his wife Merit were found intact in an undisturbed tomb in western Thebes near the ancient workers' village of Deir el-Medina. Previous MDCT (this abbreviation needs spelling out) investigations showed that the bodies of Kha and Merit did not undergo classical royal 18th Dynasty artificial mummification, which included removal of the internal organs. It was, therefore, concluded that the retention of the viscera in the body, combined with an absence of canopic jars in the burial chamber, meant the couple underwent a short and shoddy funerary procedure, despite their relative wealth at death. Nevertheless, all internal organs - brain, ocular bulbs/ocular nerves, thoracic and abdominal organs - showed a very good state of preservation, which contradicts the previous interpretation above. In order to better understand the type of mummification used to embalm these bodies, both wrapped mummies were reinvestigated using new generation X-ray imaging and chemical microanalyses Here we provide evidence that both individuals underwent a relatively high quality of mummification, fundamentally contradicting previous understanding. Elucidated "recipes", whose components had anti-bacterial and anti-insecticidal properties, were used to treat their bodies. The time and effort undoubtedly employed to embalm both Kha and Merit and the use of imported costly resins, notably Pistacia, do not support the previously held view that the two individuals were poorly mummified. Despite a lack of evisceration, the approach clearly allowed their in situ preservation as well as affording a fairly successful mummification.

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Introduction

On February 15 1906, the archaeologist Ernesto Schiaparelli (1856–1928) and the Inspector of Antiquities, Arthur Weigall (1880–1934), opened the door of the inner chamber of an unplundered tomb (TT8) located on the cliffs surrounding the ancient village of Deir el Medina, Egypt. Tomb TT8 was revealed to be the burial and undisturbed resting place of the 18th Dynasty royal architect Kha and his wife Merit, the Mistress of the House [1].

The name of the royal architect, his social status, and details of his private life, were already known to scholars by the early years of the 19th century, Bernardino Drovetti (1776–1852) having discovered Kha and Merit's decorated funerary chapel, surmounted by a pyramidion, and their funerary stele on the top of Deir el Medina's western cemetery. Kha and Merit's stele (Turin Museo Egizio Cat. 1618 RCGE 5673) was already part of the Drovetti Collection at the Turin's Egyptian Museum circa 80 years before the tomb itself was uncovered [1–3].

Due to its unexpected location, some 25 meters north of the family funerary chapel (coordinates apr. 25.7°N 32.6°E), the tomb of Kha and Merit, the most intact non-royal tomb from the New Kingdom, had never been violated. Along with the two large wooden sarcophagi containing the mummies of the architect and his wife, over 500 hundred items, all of which would have served Kha and Merit in the Afterlife, were recovered from the tomb. As one of few Egyptian burials to remain entirely undisturbed since the time it was sealed, the discovery is of greatest importance for the reconstruction of funerary customs of the New Kingdom. It also represents a seminal contribution to a knowledge and understanding of funerary customs of non-royal individuals at this time. [4]

Despite 'Egyptian mummification' often being seen as a very narrow and specific definition, even within the study of ancient Egypt itself, the reality is that it evolved, and indeed regressed, over time. Within this there were inevitable variations, despite some general consistencies, and as a process it was confined to the privileged elite for much of its history—through whose eyes much of the received wisdom continues to be seen—with the particular status of individuals inevitably affecting the treatment they ultimately received.

When considering the available non-scientific evidence, there are few ancient Egyptian texts on embalming, all of which are late in date, when Egypt was no longer governed by a native monarchy. Outside these sources, secondary textual evidence for mummification is provided by the classical writers Herodotus [5], Diodorus Siculus [6], Strabo [7] and Pliny [8], although these are also relatively late in date. The most important of these is that of Herodotus [5] (c. 450 BC), although archaeological evidence shows that even this earliest of accounts was centuries after the high point of the embalmers' 'art' c.1350 BC [9,10]. Consequently, the lack of a proper and full written record of the process by the ancient Egyptians themselves means the nature of the embalming agents in particular, remains obscure.

Where scholarly and scientific studies on Egyptian mummies have been carried out they have historically tended to have an anatomical and medical perspective [11,12], which while unquestionably providing valuable insights has necessarily limited the questions it is possible to answer, particularly in connection with the embalming materials themselves. Again, although providing valuable information on funerary practices and disease, studies of Egyptian mummies largely continue to exclusively employ imaging techniques; X-raying, CT scanning and MRI [13–16], which necessarily cannot identity the embalming agents themselves.

Although relatively modest in number, modern investigative chemical techniques applied to securely provenanced and dated mummies and their embalming materials [17–22] have provided insights into the complex organic materials used in mummification during Egypt's pharaonic period (c. 2900–332 BC) [23]. The relevance of these chemical studies for Egyptian mummification and embalming has also been further demonstrated recently with the

investigation of prehistoric Egyptian burials pushing back the origins of Egyptian mummification by some 1500 years to the Late Neolithic period [24].

On New Kingdom mummification specifically, it is seen as a time when embalming became relatively standardised [25], involving, in order: removal of the brain, removal of the internal organs, sterilization of the body cavities and internal organs, embalming the internal organs, temporarily packing the thoracic and abdominal cavities, dehydrating the body with the salt natron, removing the temporary packing, repacking the body with permanent packing material, anointing the body, coating the body with embalming 'resin', and wrapping the body in linen, with amulets and embalming agents applied to the linen as the body is wrapped. Although the omission of some or all of these processes for a 'traditional' Egyptian mummy has been considered previously [26], a focus on royal mummies in particular means there is less of an understanding of the exact procedures and materials applied to individuals of the lower elite during this time, and where their study has occurred, a rigorous investigation of the embalming materials employed has not been part of the research [26]. This has led to the erroneous assumption that the lower Egyptian elite were not embalmed, which given the symbolic importance of the process is of fundamental significance.

Here we employ an investigative approach combining the benefits of imaging techniques with those of chemical investigations in order to provide truly meaningful insights into not only some of the physical procedures employed by the embalmers, but also—and crucially—the nature and identity of the embalming agents themselves.

If the embalming procedures used to preserve Kha's and Merit's bodies are compared with those used for Yuya and Thuyu, Queen Tiye's parents, sound differences emerge. Yuya and Thuyu's tomb (QV36) represent one of the few non-royal burials from the Valley of the Kings dating back to the late 18th Dynasty. Although their tomb was plundered several times in antiquity, the mummies have not substantially been damaged.

Recent MDCT investigations carried out on the Royal Mummies (18th to the 20th Dynasties) showed that both Yuya and Thuya underwent excerebration and evisceration although to a different extent. Sagittal CT reconstruction in midline of head of Thuya (18th Dynasty) showed a defective base of anterior cranial fossa. The skull showed to be almost empty with a complete removal of brain except from a few dural remains. No embalming materials were introduced intracranially. An attempt to remove Yuya's brain was performed, similarly, by using the transnasal route. However, only a small portion of the brain was extracted, the majority of the desiccated brain having been left in situ and treated with resinous compounds [27]

Similarly, Saleem and Hawss have provided evidence that Yuya and Thuyu had been eviscerated and differently packed so to provide them with a life-like fullness of their faces and bodies, The use of subcutaneous packing in Yuya and Thuyu's mummies had already been described by G. E. Smith who could, however, only perform a visual inspection. CT scanning allowed to see the different distribution of the subcutaeous packing. While Yuya's remains were extensily packed (face, neck and torso), the use of subcutaneous packing in Thuyu was limited only to her face [28].

Previous investigation indicated that neither Kha nor Merit had undergone the classical 18th Dynasty artificial mummification seen in royal mummies of the period. The findings presented produced a series of speculations including the suggestion that both corpses, although adorned with beautiful jewellery, had undergone a shoddy funerary treatment [29]. Indeed, it has been accepted that Kha and Merit underwent no embalming or mummification at all, but were merely wrapped in linen [30,31].

The aim of the reassessment was to provide new insights into the thanatological treatment of these non-royal elite, individuals, which resulted in the moderately successful preservation of their corpses some c. 3400 years later.

The historic background

Kha is thought to have originally been a man of modest background who may later have enjoyed a successful career on the basis of merit. He rose to the rank of Director of the Royal Works in Deir el Medina where he oversaw the construction of the royal tombs. He served three 18th Dynasty Kings: Amenhotep II (1424–1398 BC), Thutmose IV (1398–1388 BC) and Amenhotep III (1388–1348 BC) and died during the reign of the latter Pharaoh. From the style of the funerary objects found in the burial chamber, Kha's death occurred a number of years before those of Yuya and Thuju—Queen Tiyi's parents, the spouse of King Amenhotep III—whose plundered tomb (KV46) was discovered by Quibell in the Valley of the Kings on February 5 1905 [32].

Based on the items found in their burial—500 objects including five nested coffins, some of which were gilded, full sets of linen clothing and monogrammed underwear, a variety of types of food and two of the earliest known examples of the Book of the Dead, complete with vignettes, it can be assumed that Kha and Merit were a wealthy couple. They had three known children: two sons, Amenemopet, Nakhteftaneb and a daughter, Merit II. Amenemopet followed his father's career while nothing is known about Nakhteftaneb. Merit II became a Singer of Amun. All of them survived their mother [33]. Merit passed into the realm of Osiris, Lord of the Dead, long before Kha. Her own coffin was probably not finished when she died unexpectedly, since she was buried in Kha's anthropomorphic coffin. Due to her being much shorter than her husband, Kha also donated some of his monogrammed linen fabric so that the corpse could be safely accommodated inside the coffin (Fig 1). Merit's inner coffin was then placed into a black shiny rectangular outer coffin. The two anthropoid coffins of Kha are of exceptional quality. His outer coffin is also covered with a shiny black coating, while the face, the hands, bands of inscriptions and figures of funerary deities are of gilded gesso. The inner coffin is fully gilded. These coffins are extremely similar to those of Yuya and Thuyu [32]. The shiny black material covering the outer coffins of both Kha and Merit has previously been described as 'bitumen' [1,3], but this has been revised as part of this study.

Materials and Methods

The catalogue numbers of the investigated mummies are:

1. Mummy Turin Fondazione Museo delle Antichità Egizie N 13015 Suppl. 8431 from tomb TT 8, identified as Kha;
2. Mummy Turin Fondazione Museo delle Antichità Egizie N 13016 Suppl. 8471 from tomb TT 8, identified as Merit.

Over 500 items found in Kha's and Merit's burial chamber, which bear their names, and that are currently exposed in their reconstructed tomb in Turin's Fondazione Museo delle Antichità Egizie were observed in order to gain further information on their social status and in life possessions [1]

Since the corpses of Kha and Merit are completely wrapped, their investigation relied upon the use of non-invasive imaging technology, minimally destructive analysis of small areas where some limited damage had already occurred, and small samples from Kha and Merit taken historically since their arrival in Turin in 1906 and held in museum storage. This approached aimed to maximise information gained while minimising the impact on the invaluable mummies of Kha and Merit. Both mummies had been previously subjected to conventional X-rays in 1966 [34,35] and Multidectector Computed Tomography (MDTC) in 2001 [29,36]. The integral 2001 CT scan dataset of images is not publicly accessible. Therefore, direct

Fig 1. Digital X-raying of Kha (upper); the mummy of Merit (lower). Merit's coffin, which is too large for her size and originally belonged to her husband.

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comparisons between the CT scan images and current X-ray imaging couldn't be performed. The previous CT report suggested that both corpses underwent a shorter thanatological treatment, presumably compared to royal individuals of the period, but still allowed all inner organs—brain included—to have been preserved reasonably well [29]. Nevertheless, there was no meaningful attempt to fully explain the nature and significance of this 'shorter procedure' with respect to the possible practical and religious significance of this unusual type of mummification.

In January 2014, a state-of-the-art mobile digital X-ray imaging (EXAMION PX 60 HF; max. output 3.2 kW, Voltage range 40–100 kV, Exposure range 0.4–100 mAs) was performed in situ at Turin's Fondazione Museo delle Antichità Egizie (Fig 1).

The new set of non-invasive investigations detailed above was coupled with minimally invasive organic and inorganic chemical investigations. These were performed on very small samples (typically ~0.1 g) from both individuals outer wrappings, and material in museum storage, shedding significant new light on their mummification process. Very small samples of the shiny black coating covering the outer coffins of both Kha and Merit were taken from each to establish the nature and origin of the material and to determine whether both coatings of 'black bitumen' were related in composition and technological production.

Results

The mummy of Kha (Turin N 13015 Suppl. 8431)

Previous investigations (1966, 2001). Kha was laid out in a supine position with his arms extended along the sides and the hands laid flat over the pubis [29]. Previous stature estimates indicate, respectively, that the architect was approximately 171 cm [29] to 172 cm tall [34]. Martina et al. described Kha as a possibly overweight and diseased man of circa 60 years of age at the time of his death, affected by diffuse atherosclerosis and cholecystitis [29,36]. The state of skeletal preservation was described as excellent whereas the dentition was described as generally poor. An intra-vitam fracture of the L1 vertebra and severe arthritis level with spine and knees were also described [29].

With regards to the funerary treatment, previous reports indicate that Kha had neither been excerebrated nor eviscerated. Due to this and to the absence of canopic chest associated with the burial, it was claimed that his corpse underwent a "poor standard of mummification". Although it was claimed that his corpse was poorly mummified, the preservation of the internal organs—brain included—was reputed to be optimal [29].

Re-assessment of Kha's mummy (2014)

Stature, age and pathologies. The mummy of Kha measures 24 x 43 x 168 cm (depth, width, length). He was a mature adult in his fifties to sixties when he died (Figs 2 and 3) based on the extensive alterations of the lumbar spine and the poor dental health. His suggested biological age at death is consistent with the known biography.

Except for a few pathological conditions observed on the spine (Figs 4 and 5), Kha's skeleton can be compared to that of a modern day healthy old man. An unusual structure is observable level with the ventral parasternal side of the first rib (Fig 5); this can be either due to a bone overgrowth or to the effect of overlaying soft tissue. Due to the unavailability of previous CT scan images, more in-depth speculations to ascertain the nature of the above structure cannot be performed. Possible remnants of the bronchi and shrunken lungs can also be seen on the X-rays (Fig 5).

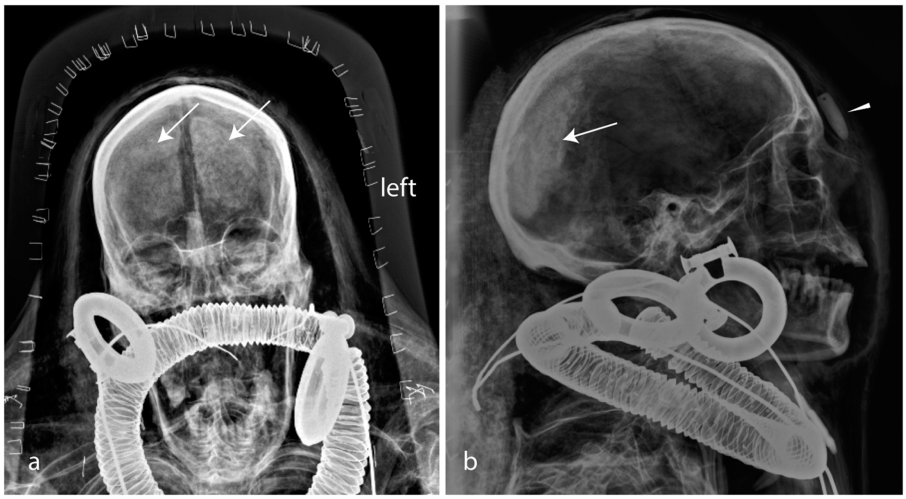

Fig 2. Kha's skull a) frontal (ap) and lateral b). Note the shrunken brain remnants (arrows). The shape of the nasal bone indicates an aquiline profile. A snake's head (made of stone) is clearly visible at Kha (arrowhead, lateral view). A dense oval plate (amulet?) is visible above the "Gold of Honour" collar. The collar of honour is made of gold discs. The broad earrings are made of ca. 1 mm thick gold foil. Imaging parameters a): 70kV, 3,2mAs; b) 70kV, 8mAs.

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At the right elbow, an enthesopathy is evident at the insertion of the triceps brachii (Fig 6); signs of spondylosis with several osteophytes are observable over the entire lumbar spine (L1/2, L2/3, L3/4, L5/S1) (Fig 5).

The L1 vertebra (first lumbar) is malpositioned and deformed with the distal end plate slightly oriented towards the left. A gap in the L1 vertebra, which also affects the Th12 (the last thoracic vertebra), is observable and is linked to post-mortem damage (Figs 4 and 5). Some slight degeneration is visible in the knees. The cause of Kha's death remains unknown, there is no evidence of a fatal trauma.

Kha's dentition. Anterior-posterior, lateral and half-axial projections, although not ideally suited for diagnosis of dental pathologies, were performed in order to gain overall information on the state of preservation of Kha's dentition (Fig 2). The mouth of Kha is open to a significant extent. In the upper jaw, the central upper frontal incisors according FDI classification [37] (11; 21) and lateral (12; 22) incisors are still preserved although both lateral incisors (12, 22) seem to have peri-apical osteolysis. Upper premolars and molars, except some root remnants, were lost intra-vitam. No post-mortem tooth loss could be identified within the bandages. Because of the missing teeth in the upper maxilla, the dentition was severely limited in its functions.

In the lower right mandible, teeth are present from the incisors to the first premolar (41,42, 43, 44, 45) and on the left side to the elongated second molar (lower left side 31,32,33,34,35,37 and upper left 26). In these X-rays, carious lesions were not detected and the status of the peri-odontium could not be evaluated. Because of the missing teeth in both the upper and lower jaws, the dentition was severely limited in its functions. Thus, an overall poor state of preservation of Kha's dentition was observed.

The mummy of Merit (Turin N 13016 Suppl. 8471)

Previous investigations (1966, 2001). Merit was laid out in supine position with extended arms and the hands nearly crossed over the pubis [29]. Previous stature estimates indicate, respectively, that she was 148 cm [29] or ca. 160 cm tall [34]. Based on the relative complete

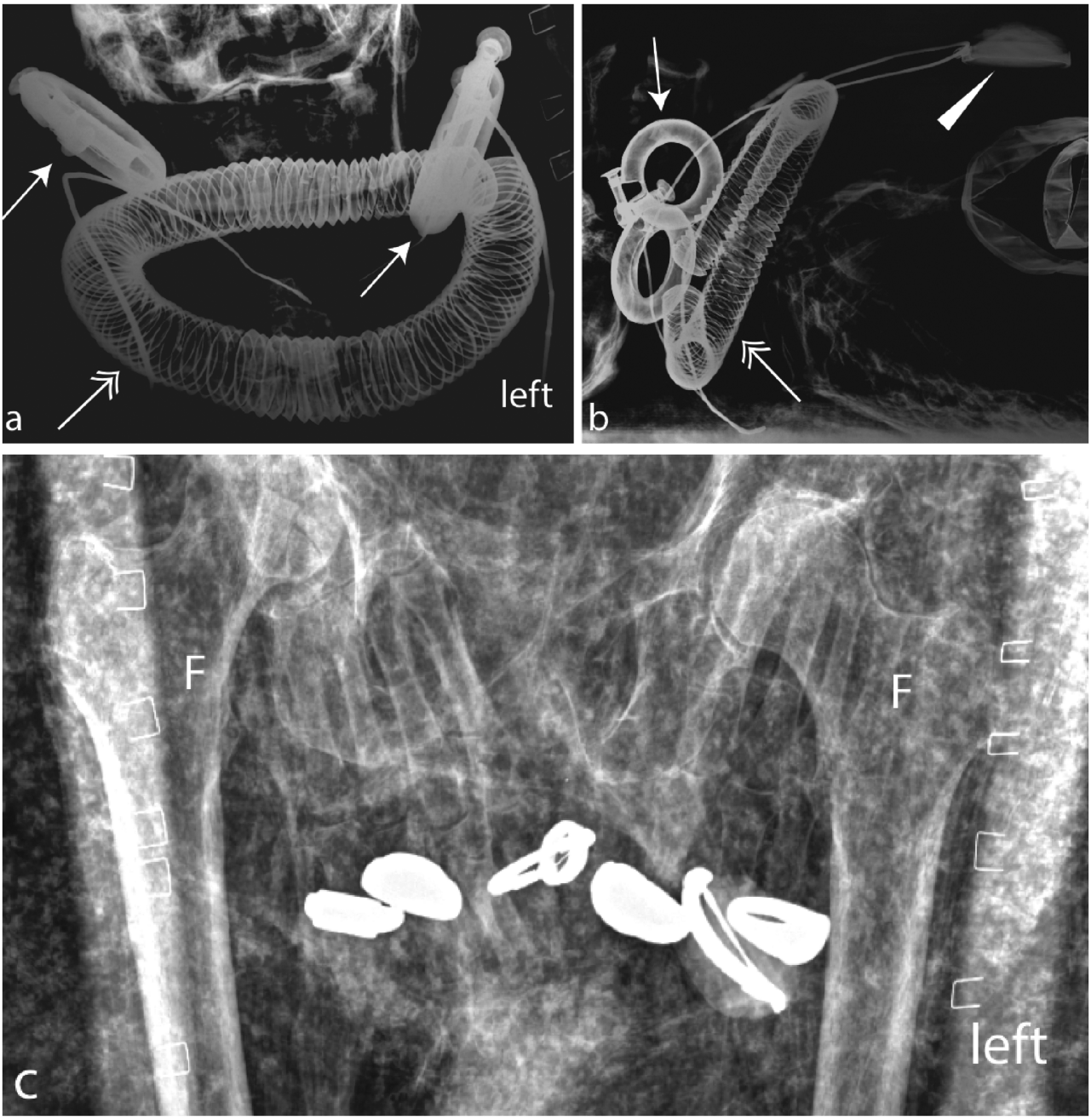

Fig 3. Kha's jewellery: a, b) Kha wears a wide collar (double arrow), large ear-rings (arrows) and a large heart scarab on a metal rod (arrowhead); c) the hands laid on the pelvis. Six finger rings are visible. F. Femoral bone. Imaging parameters: a): 80kv, 8mAs; b): 100kV, 10mAs; c): 70kV, 5mAs.

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dentition, Martina et al. estimated that Merit died aged 25–30 years old. CT scans showed that, similarly to Kha, she had been neither excerebrated nor eviscerated. Eye bulbs could not be identified as artificial eyes, made of a radio-opaque material, were positioned on the orbits before the funerary mask was positioned on her face and chest. The state of preservation of the skeleton was judged as poor; this was due to a series of possible post-mortem fractures and resulting displacement of the bones, especially those level with the chest and the pelvis.

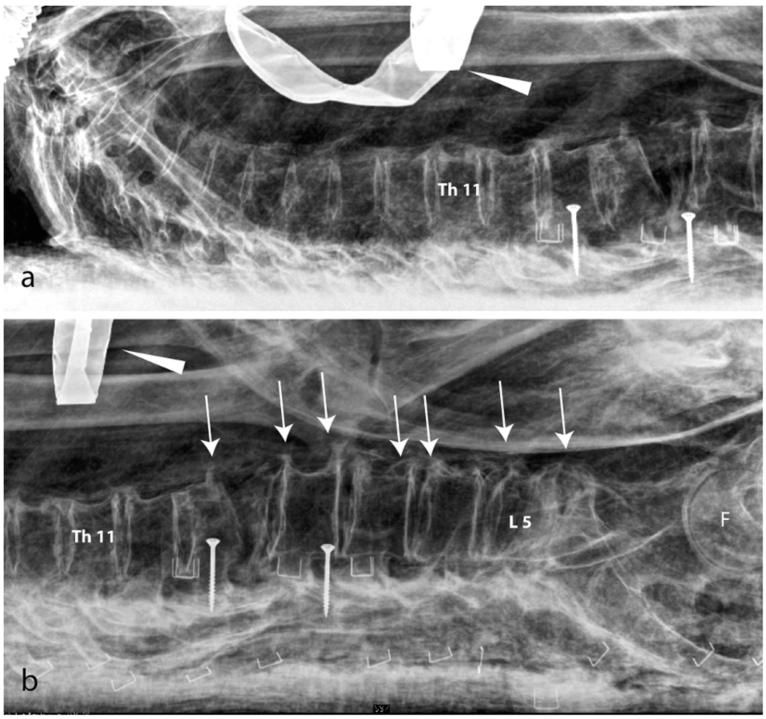

Fig 4. Kha. Lateral view of the thoracic (a) and lumbar (b) spine. The vertebral column shows a dislocation between L1 and L2 (post-mortal change). Degenerative changes (spondylophythes, arrows) are visible in the lower lumbar vertebra, suggesting that Kha was of advanced age. Arrowhead: funerary jewellery, as seen in Fig 3. F: femoral head. Imaging parameters a): 70kV, 8mAs, b): 100kV, 8mAs.

doi:10.1371/journal.pone.0131916.g004

Re-assessment of Merit's mummy (2014)

Stature, age and pathologies. The remains of Merit measure 10 x 34 x 147 cm (depth, width, length). She was an adult when she died and, based on the absence of degeneration of her bones, her age at death can be placed at approximately 25–35 years old (Fig 7).

The tibia of Merit measures on X-ray c. 42.5 cm. Using the X-ray correction factor (c. 1:1.15), the true length of the tibia is approximately 37 cm. Using different body height reconstruction formulae, the realistic body height of Merit is estimated to between 149 cm [29,34,38] (Trotter Gleser, female Caucasian) and c. 162 cm [39] (Pearson female, prehistoric). The female Black African formula of Trotter and Gleser producing an unrealistic tall reconstruction of c.168 cm by over-emphasizing the distal limbs. Therefore a stature of 160 cm appears to the more realistic [40].

The mummy shows very significant post-mortem damage. The thorax is massively depressed and the rib cage is broken (fallen ribs can be identified in the abdomen) (Figs 8 and 9). At the right elbow, a luxation of the radius and ulna is observable and the right wrist is luxated. The spine is disrupted level with T10/1 and L4/5 and the vertebrae T11/L3 are dislocated and rotated axially apr. 45°. The sacro-iliac joint shows a dislocation and the pelvis is disrupted (luxation of the left hip and disarticulation of the sacrum) (Figs 8 and 9). Merit's cause of death is unknown. The unusual dislocation of the ribs and of the vertebral column argues against an intra-vitam trauma.

Merit's dentition. Anterior-posterior, lateral and half-axial projections, although not ideally suited for diagnosis of dental pathologies, were again performed in order to gain overall information on the state of preservation of Merit's dentition. Merit's mouth is slightly open. In

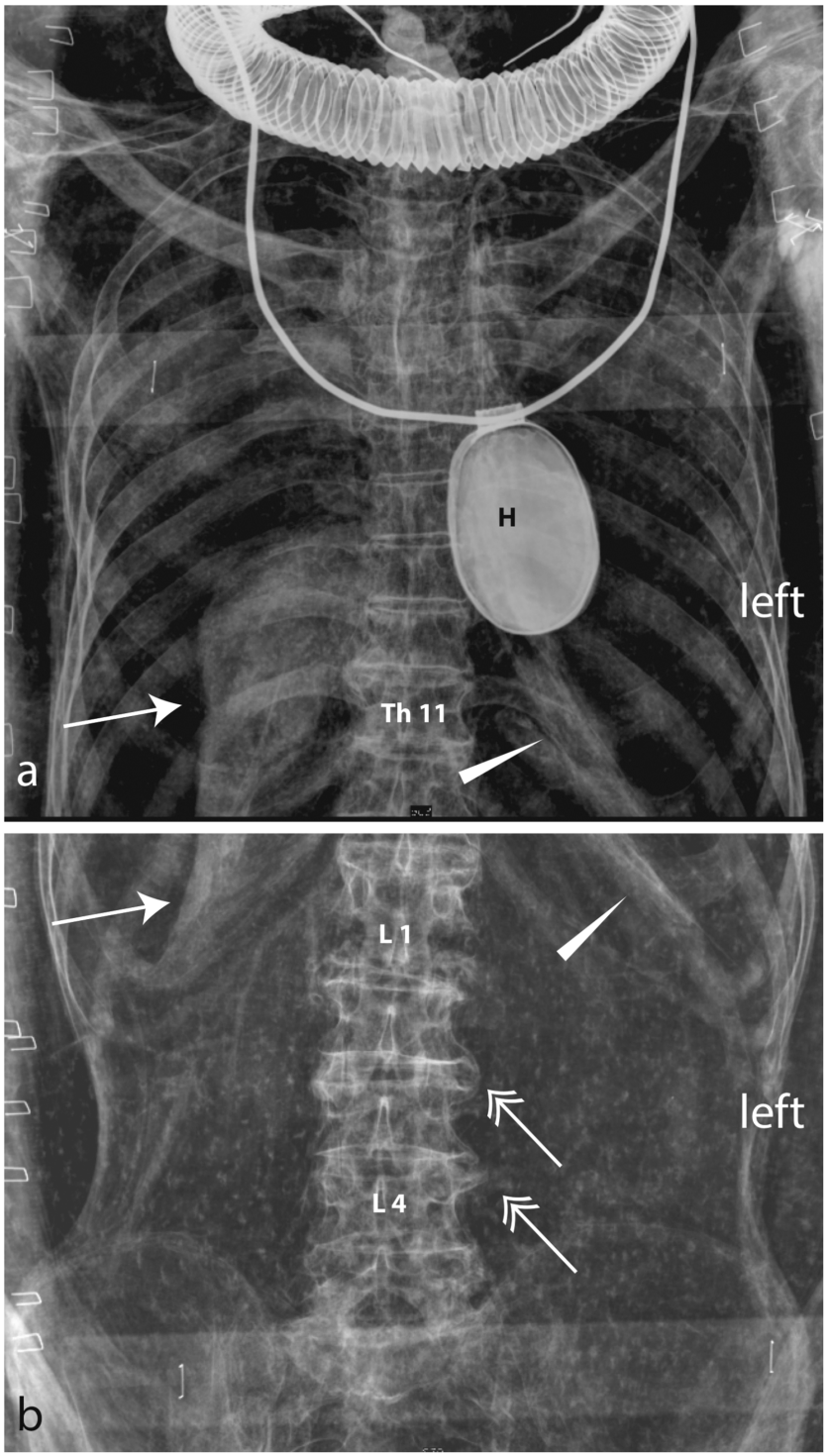

Fig 5. Kha. Frontal view (ap) of the thorax/abdomen. Possible remains of the shrunken lungs (arrow) and a possible bronchus rest (arrow head) are observable. The lower lumbar vertebrae show degenerative signs (spondilophythes on their left side). H: heart scarab. Imaging parameters: a & b): 80kV, 8mAs.

doi:10.1371/journal.pone.0131916.g005

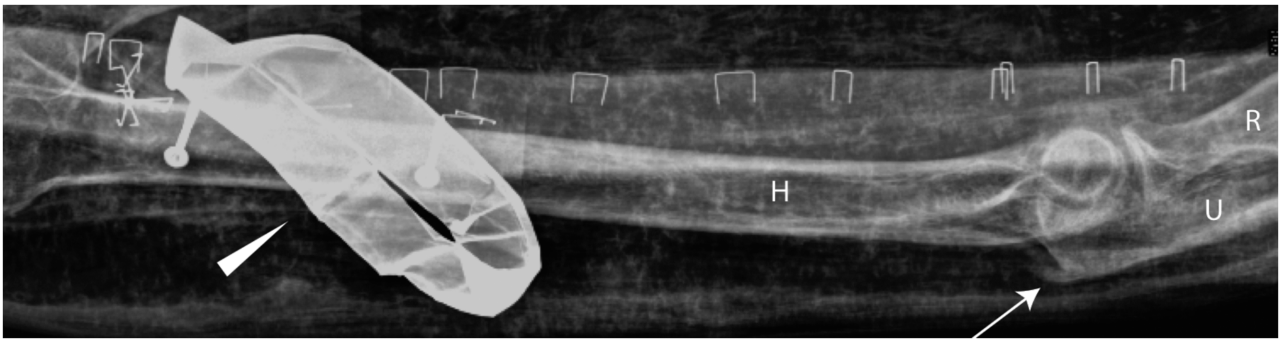

Fig 6. Kha: The right elbow shows an obvious enthesopathy of the insertion of triceps brachii muscle (arrow). Arrowhead: A golden foil was wrapped around his upper arm (funerary jewellery). F: humeral bone. U: ulnar bone. R: radial bone. Imaging parameters: 70kV, 3,2mAs.

doi:10.1371/journal.pone.0131916.g006

the maxilla, a premolar (15) and the last molar (18) were lost ante-mortem; upper left premolar (25) shows a deep carious lesion on its mesial and distal surfaces and the second molar (27) possibly on its distal surface. In the right mandible the lower right canine teeth (43), and the subsequent premolars (44 and 45), and on the left lower side the first premolar (34) were probably lost intra-vitam. According to Melcher et al. [41], the abrasion of the visible wisdom teeth (38, 48 and 28) is grade 1 whereas the other molars display grade 2–3. Only minor alveolar bone loss is observable. Apart from some impairment, her dentition was still functional.

The jewellery of Kha and Merit

In order to acquire further details on the construction of the jewellery, the X-ray analyses were focused on using energies (80-100kV instead 60kV) most suitable for the materials they were likely to be more dense (e.g. made of metals). The type of metal commonly used in high rank burials was gold. This statement is fully corroborated by textual evidence and by comparisons with similar jewellery found in royal tombs dating to the same period (e.g. Amenhotep III).

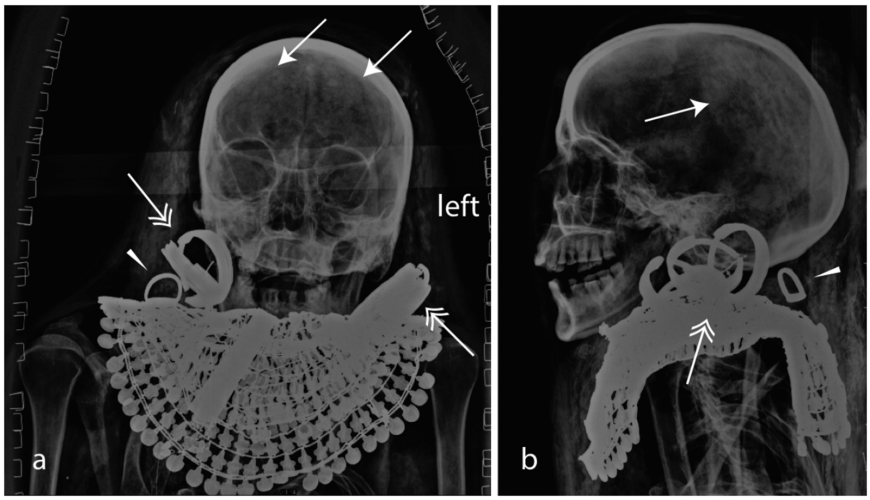

Fig 7. Merit: a) frontal view and b) lateral view of the head. Inside the cranium, remnants of the shrunken mummified brain are visible (arrows). The dentition supports the suggested age of ca 30 years. Merit probably also had a prominent aquiline nose. An Usekh-collar, two ribbed earrings (double arrow) and a dislocated finger ring that moved behind the neck (arrowhead) are observable.

doi:10.1371/journal.pone.0131916.g007

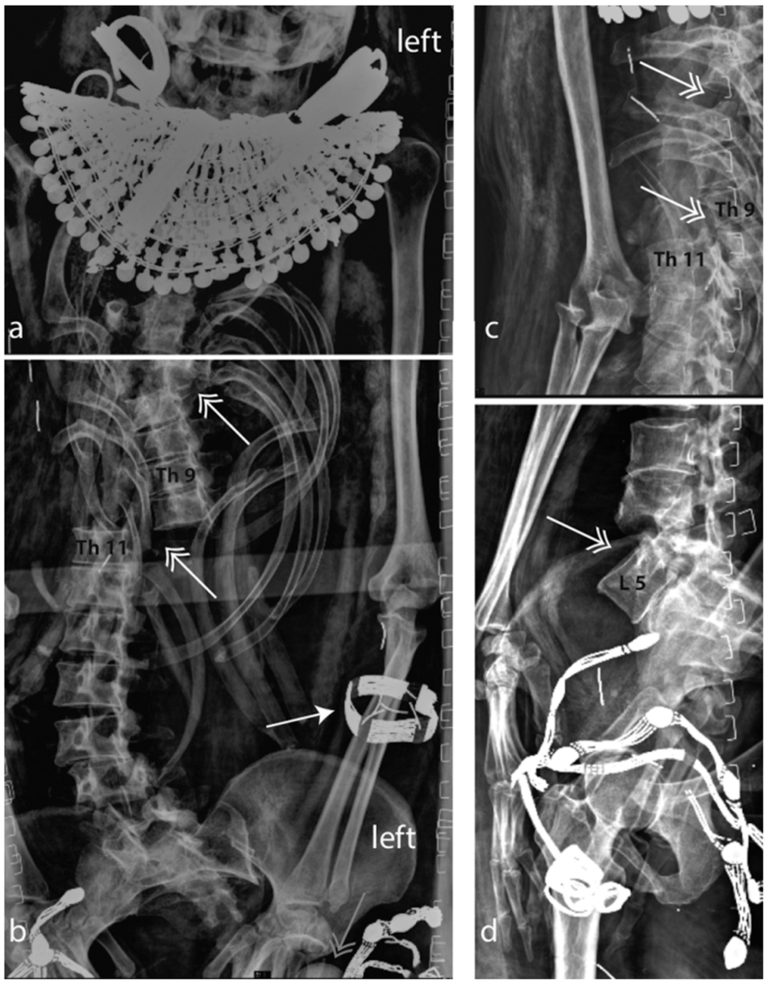

Fig 8. Merit. a) frontal and b) lateral view of the vertebral column and the pelvis. A massive post-mortal disruption of the vertebrae (double arrows) and ribs are visible. The left hip is luxated (red double arrow). No degenerative were observed. Merit wears a fine bracelet on her lower arm (arrow).

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Fig 9. Merit's total skeleton reconstruction.

doi:10.1371/journal.pone.0131916.g009

Kha and Merit died during Amenhotep III's reign and were highly reputed members of their community. Therefore, since they were 18th Dynasty high status individuals, it can be confidently assumed that the jewels they wear are made of gold as well [42].

Kha's jewellery. Kha wears extensive and large-sized jewellery (Figs 3 and 5) and he was probably dressed in a kilt or a bag-tunic following the New Kingdom's fashion [43–45]. A detailed list of his ornaments is given below.

Golden ear-rings (jewellery worn in life and death). Kha is one of the earliest known examples of an Egyptian man wearing large ear-rings [35,42]. The two half-shaped earrings are made of gold sheet, 1mm thick (Fig 3). This design was very widespread during the 18th Dynasty [42,44,46,47] and the custom of wearing ear-rings, which appeared at the dawn of the New Kingdom and this fashion was likely introduced from Nubia [35]. Two examples of a similar type of ear-rings have been identified in a 17th Dynasty female burial in Qurna [42] and in an 18th Dynasty burial [46].

Gold of honour collar (jewellery worn in life and death). Kha has a ´Gold of Honour´ collar, the prestigious reward that distinguished ancient Egyptians received from their King. It is made of a single string of golden discs [33,48] (Fig 3). A five-string ´gold of honour´-collar was identified in King Psusennes I's Tanis Tomb III (Cairo Mus. JE 85751) and weights 6.315 kg [49,50]. It is therefore be estimated that the weight of Kha's collar ranges between 1–1.5 kg.

The ´gold of honour´-collar is widely represented in the iconography (e.g. statuary, reliefs, wall paintings), for example Sennefer's three-row collar in a wall painting in his tomb TT 96 [51,52] or the four-row collar he wears on his statue dyad with his wife Senai (Cairo Mus. JE 36574 CG 42126 [51]. Men and women alike received this royal award as shown in the Amarna tomb reliefs of Ay and his wife Ty, who are both decorated with ´Gold of Honour´ collars given by King Akhenaten [48,53]. Horemheb received several of these awards when he was a general serving Tutankhamun as wall reliefs from his Saqqara tomb attest [48,54].

Six finger rings (jewellery worn in life and death). Previous X-rays identified five finger rings [33]. New X-ray imaging shows that Kha actually wore six finger rings. In Fig 3, the following rings can be appreciated: i- one rectangular plate-shaped gold ring; ii- one oval plate-shaped gold ring [46]; iii- a gold ring surmounted by a flexible oval scarab; iv. a second oval plate-shaped gold ring [46]; v. a gold ring with a rectangular plate which originally might have been made of faience or stone (only the metal rod holding it is visible as the stone is destroyed) [46]; vi. a gold ring with an oval cartouche [46]. All the described finger rings were popular in the New Kingdom and were worn in both life and in death.

Heart scarab (funerary jewellery). A large heart scarab attached to a long radio-dense rod, possibly a wire of gold or a gold-plated spun chain (Figs 3 and 5), has been identified on Kha's chest [35]. It can be expected that an inscription with spell 30B from the Book of the Dead is present on the base of the scarab based on parallels. This jewellery was specially made for the burial of Kha.

Amulet of Isis (funerary jewellery). Underneath the collar, is a tyet-amulet (Isis-blood) was observed, normally as described in the Book of the Dead (Spell 156), this amulet was probably made of a red carnelian stone or another red stone (Fig 3). These amulets were a normal part of the funerary jewellery [42,46].

Serpent amulet (funerary jewellery). The ureret-amulet (Egyptian: Wrr.t) in the form of a serpent's head is generally made of carnelian; here it is unusually placed in the middle of Kha's forehead (Fig 2). According to tradition, this amulet should be fixed at the neck of the dead to support his breathing in the Afterlife [4,42]. The forehead position in the case of Kha is identical to that of the uraeus serpent in pharaohs' burials. Fletcher has speculated that by placing the amulet on his forehead, the people of Deir el-Medina honoured their 'boss' Kha as a ´local pharaoh´ [55].

Golden foil around the upper arms (funerary jewellery). On each upper arm, Kha displays twisted lengths of thin gold foil (Fig 5). Jewellery made of gold sheet are known from royal burials (e.g. the vulture collar from KV 55 or collars from the burial of Tutankhamun in KV62) [56–58]. Mummies covered with gold foil are a typical of the pre-Amarna, Amarna and Ptolemaic periods. Therefore this type of material in Kha's burial is consistent with others from the reign of Amenhotep III (i.e. pre-Amarna).

Merit's jewellery. Unlike Kha, Merit only wears the type of jewellery worn in life, with no funerary amulets associated with her body. This might indicate that her death was sudden and unexpected and that her funerary jewellery and coffins were not ready when she passed away. It can be expected that she was dressed in her finest clothes in preparation for the Afterlife. A detailed description of Merit's jewellery is given below.

A broad collar (jewellery worn in life and death). Merit wears a wide collar known as an Usekh-collar, jewellery whose use is testified from the Old Kingdom onwards (Figs 7 and 10) [42,51,59]. The collar is made of gold inter-spaced with gemstones whose exact nature cannot be established (e.g. amethyst, lapis lazuli, carnelian, turquoise faience). A collar with similar elements but a different counterweight was found in the burial of Thutmosis' III foreign wives [42,46,60–62].

Two pairs of golden ribbed-earrings (jewellery worn in life and death). Merit wears two sets of ribbed-type ear-rings whose typology is known from mid-18th Dynasty (Fig 7) [42,46]. Double-pierced ears were a fashion among elite women of the mid-18th Dynasty, as in the case of the mummies of both Thuyu and the Younger Woman who is most likely Nefertiti [63].

Four finger rings (jewellery worn in life and death). Merit's hands were adorned with four rings: i. two rings bearing a fixed oval plate; ii. two rings with a flexible oval plate [42,46]. One of the rings with a fixed oval plate fell from her finger and is displaced behind the collar (Fig 7; behind the cranium). This position confirms the hypothesis that Merit's corpse suffered a post-mortem damage.

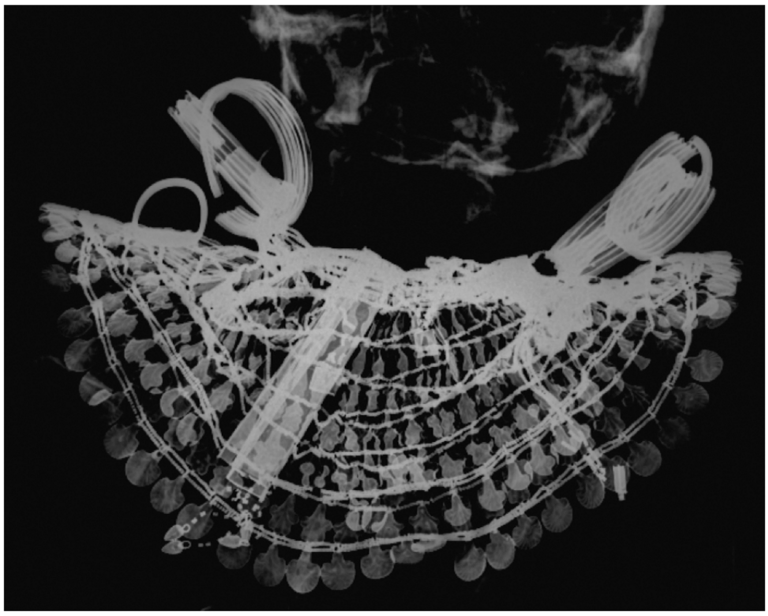

Fig 10. Merit still wears the Usekh-collar

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A girdle (jewellery worn in life and death). A girdle made of fine beads and metal cowrie shell-shaped parts (Fig 10) is observable level with Merit's waist. These girdles became popular from the Middle Kingdom onwards and many variations are known, for example the girdle of the 12th Dynasty Princess Sithathoriunet which is made of amethyst beads interspaced with golden leopard heads [42,46], or the girdle worn by one Thutmosis III's foreign wives- mid-18th Dynasty- which is composed of red glass beads interspaced with gold fish elements [46,60,62].

Necklace of fine beads (jewellery worn in life and death). Merit also wears a three-row necklace made of very fine beads connected by fine golden tubes [33]. The necklace has broken into pieces and parts of its dislocated elements appear near her ankles (Fig 7).

A bracelet made of beads (jewellery worn in life and death). This elegant bracelet follows the same style of the necklace and of the girdle. It is highly likely that they formed a "parure" (Fig 8). The bracelet is made of around 10 rows of fine beads strung between golden elements and a locking end-piece. This type of bracelet was used from the Middle Kingdom onwards, for example a similar bracelet was associated with the burial of Queen Aahotep dating to the beginning of the 18th Dynasty [42].

All the jewellery objects worn by Merit were designed to be worn during her lifetime. From the overall re-appraisal of Merit's jewellery, excluding the finger rings, it can be hypothesised that her body was adorned with a double set of jewellery combinations: i. the Usekh-collar and one pair of ribbed earrings; ii-the girdle, the bracelet and a second pair of ribbed earrings. However, although New Kingdom's iconography shows that the large ribbed ear-rings were not normally worn as double earrings, it should again be noted that double-pierced ears, allowing for the wearing of double earrings, were a fashion among elite women of the mid-18th Dynasty, as in the case of both Thuyu and the Younger Woman who is most likely to be Nefertiti [63–67]. Notably, Merit was not equipped with funerary amulets, possibly due to her unexpected death, indicated by the use of her husband's coffin.

The outer coffins of Kha and Merit

Chemical analysis of the black coatings (gas chromatography-mass spectrometry (GC-MS)) on Kha and Merit's outer coffins. As part of this current study, biochemical investigations (GC-MS) were carried out on two tiny fragments (ca. 0.01 g) taken from Kha's and Meryt's outer sarcophagi. The chemical analyses revealed that the shiny black material covering both outer coffins is not bitumen, as previously described [1,2], but a strongly heated "recipe" of mainly Pistacia resin (pitch) with far small amount of balsam and cedar oil/resin (Fig 11a and 11b), possibly mixed with carbon (charcoal), as has been previously suggested as a source of black pigment in the 18th Dynasty [68]. Despite detailed analysis, no evidence for bitumen as a component could be identified.

Overall observations on the mummification techniques

The mummification of Kha. Both the X-rays and previous CT scans reveal that the brain remains in the cranium. Although it is shrunken and has fallen to the back of the cranium, its form is well preserved and immediately recognisable. No damage of the os ethmoidale is visible. CT scans revealed the internal organs within the abdomen and thorax. New X-ray imaging revealed the brain, the bronchus and shrunken lungs (Figs 2 and 5). No inner organs had been removed contrary to the standard practice in royal mummification during the New Kingdom [4,69], explaining why the undisturbed burial had no canopic jars. The preservation of the skeleton is excellent and the eyeballs were visible on the CT-scan as well as the optical nerve and ocular muscles.

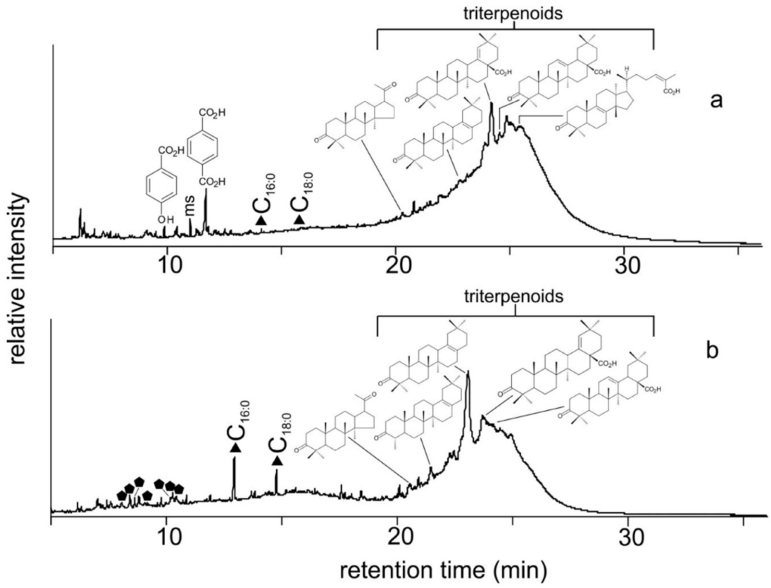

Fig 11. Reconstructed gas chromatography-mass spectrometry (GC-MS) total ion chromatogram (TIC) of the trimethylsilylated total lipid extract of (a) Kha, black coating on his outer coffin and (b) Merit, black coating on her outer coffin. Peak identities ('n' indicates carbon chain length; where shown, i indicates degree of unsaturation): filled triangles, $C_{n:i}$ indicates fatty acids; filled pentagons indicate sesquiterpenoids and their derivatives. The letters ms represent a monosaccharide. Also shown are the structures of two aromatic acids identified: 4-hydroxybenzoic acid and terephthalic acid; and the structures of six Pistacia triterpenoid compounds identified: 22,23,24,25,26,27-hexakisnor-dammaran-3,20-dione, 24,28-bisnor-olean-17-en-3-one, 28-nor-olean-17-en-3-one, moronic acid, oleanonic acid and isomasticadienonic acid.

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The mummification of Merit. As in the case of her husband, Merit's internal organs appear to have been retained within the body including her brain shrunken, but well preserved and recognisable, within the cranium. No damage of the os ethmoidale is visible. Evaluation of the internal organs within the thorax and abdomen was not possible due to severe displacement of the bones of the chest and pelvis. The condition of the skeleton is poor; many bones are broken (probably post-mortem) and displaced. Some form of textile is visible between the legs of Merit, which may represent some form of clothing or may simply be part of the wrappings.

Chemical analysis of salts used in the mummification of Kha and Merit (inorganic chemical microanalyses: 'spot tests'). White crystalline material from within Merit's shroud and mummy wrappings was chemically identified as the salt 'natron' (sodium carbonate/sodium bicarbonate, sodium chloride and sodium sulphate), regarded as the key ingredient in Egyptian mummification to 'dry out' the body.

Embalming agents used in the mummification of Kha and Merit

Chemical analysis of organic residues associated with the linen wrappings from the mummies of Kha wrappings (from base of feet). Biochemical analysis (GC/MS) carried out on a linen fragment from Kha's external wrappings indicates that the textiles were treated with a specific embalming "recipe" consisting of animal fat/plant oil mixed with a small amount of balsam/aromatic plant extract, a plant gum and a conifer resin (Fig 12a).

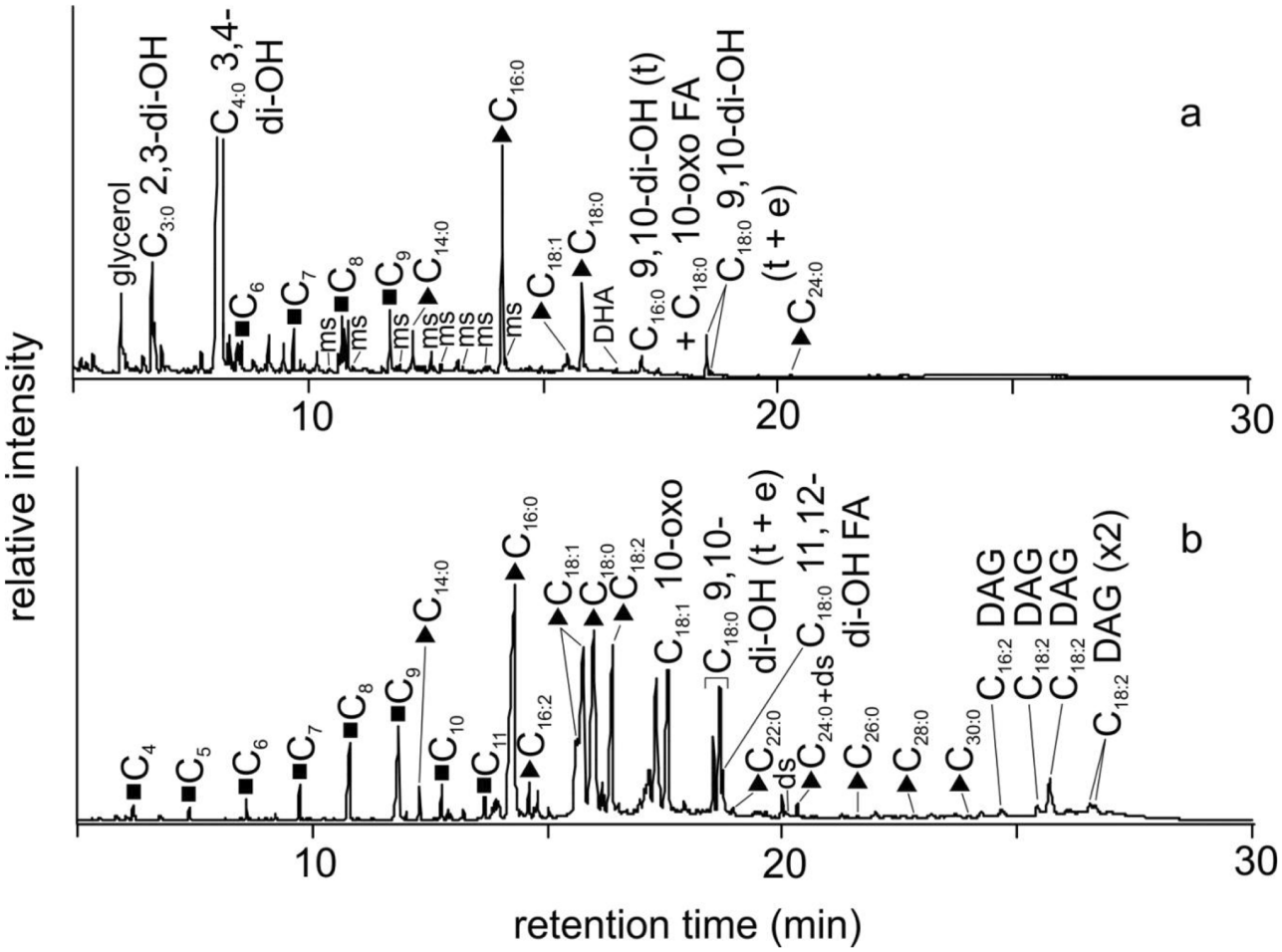

Fig 12. Reconstructed gas chromatography-mass spectrometry (GC-MS) total ion chromatogram (TIC) of the trimethylsilylated total lipid extract of (a) Kha, mummy wrappings (from base of feet) and (b) Merit, mummy wrappings (from base of feet). Peak identities ('n' indicates carbon chain length; where shown, i indicates degree of unsaturation): filled triangles, $C_{n:i}$ indicates fatty acids; filled squares, C_n indicates α,ω-dicarboxylic acids. $C_{3:0}$ 2,3-di-OH indicates 2,3-dihydroxypropanoic acid (glyceric acid); $C_{4:0}$ 3,4-di-OH indicates 3,4-dihydroxybutanoic acid (2-deoxytetronic acid); $C_{16:0}$ 9,10-di-OH (t) indicates 9,10-dihydroxyhexadecanoic acid (threo isomer); $C_{18:1}$ 10-oxo indicates a 10-oxo-octadecenoic acid; $C_{18:0}$ 10-oxo indicates 10-oxo-octadecanoic acid; $C_{18:0}$ 9,10-di-OH (t+e) indicates 9,10-dihydroxyoctadecanoic acid (threo and erythro isomers); $C_{18:0}$ 11,12-di-OH indicates 11,12-dihydroxyoctadecanoic acid; $C_{18:2}$ DAGs indicate octadecadienoyl diglycerides. The letters ms represent monosaccharides and the letters ds represent disaccharides; DHA represents dehydroabietic acid.

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Merit's mummy wrappings (from base of feet). Biochemical analysis (GC-MS) of a linen fragment from Merit's external wrappings revealed an embalming recipe consisting of a highly unusual oil (fish oil) mixed with a small amount of a balsam/aromatic plant extract, a plant gum, a conifer resin and beeswax (bitumen was absent) (Fig 12b).

Merit's red linen shroud. Chemical analysis (GC-MS) of a linen fragment from Merit's red linen shroud revealed a similar recipe to her mummy wrappings, yet there were also key differences. It consisted of the same highly unusual oil (fish oil), mixed with a small amount of conifer resin and beeswax, but additionally and most notably, Pistacia resin (the 'balsam' and gum seen in the wrappings were absent, as, again, was bitumen). The absence of the plant gum and 'balsam' on the red shroud perhaps suggests that these were seen as more practical and less symbolic than those impregnating the shroud.

Discussion

The black coatings on the outer coffins containing the mummies of Kha and Merit had been reported in the literature in both cases as 'bitumen' [1,2,70]. However, the findings presented here show that the black 'paint' was actually a mixture of ingredients, with bitumen absent. The strong heating observed from the biochemical analyses would have blackened the original resinous mixture producing a 'pitch' and giving the coffins their black shiny appearance. The two coatings are notably similar, although Kha has a small amount of plant gum not observed in Merit's, and Merit has more cedar oil/resin and animal fat/plant oil in her black coating. However, the major component constituting the black shiny coating is a Pistacia pitch, which has previously been identified as the main constituent of black 'paint' or 'varnish' on other elite funerary object from the New Kingdom [59]. Pistacia and cedar are both regarded as having been expensive commodities coming from the north-eastern Mediterranean. This finding also confirms the strong trading links existing between Egypt and Mitanni (Syria) and the important port of Byblos (Lebanon) at this time.

Observations from the X-ray images' combined with chemical investigations shed new light on Kha's and Merit's mummification procedures and contradict previous statements that neither were embalmed and that essentially no mummification whatsoever took place. On the contrary, not only were both Kha and Merit embalmed with natural products that would have involved significant cost and great effort to obtain (despite Merit's notably earlier death), but the presence of their preserved, if shrunken, internal organs and moderately well preserved bodies suggests significant efforts were made by their embalmers.

It was, therefore, argued that Kha was embalmed with a shorter and shoddy procedure [29] despite his relative wealth at death. Moreover, it has even been suggested that neither Kha nor Merit were mummified, but merely wrapped in linen [30,31]; this interpretation was also, arguably, 'corroborated' by the absence of canopic jars in the burial chamber. Nevertheless, all internal organs: brain, ocular bulbs/ocular nerves, thoracic and abdominal organs- showed a very good state of preservation [29,36]. The non-removal of viscera is not necessarily a sign of low quality mummification; even some known mummies of Queens from the Middle Kingdom were not eviscerated [13,69].

Kha's "uncommon" thanatological treatment (as well as Merit's) is not surprising if properly contextualised. Indeed, throughout the 18th Dynasty, irrespective of the economic and status differentials, the vast majority of villagers from Deir el Medina were probably not embalmed in the way normally described. The poorer people buried in the eastern necropolis were simply wrapped in linen without evisceration. Virtually no canopic jars have been found in pre-Ramesside tombs at that site [30].

X-ray images' observation coupled with chemical investigations shed new light on Kha's and Merit's mummification procedures and contradict previous statements that neither were embalmed and no mummification at all took place. On the contrary, not only were both Kha and Merit embalmed with natural products that would have involved significant cost and great effort to obtain (despite Merit's notably earlier death), but the presence of their preserved, if shrunken, internal organs and moderately well preserved bodies.

Notably, previous reports imply that Merit's corpse was embalmed "without great care" [30,31], and her brain was said to be fairly well preserved [29] Chemical analysis carried out on a linen fragment from Merit's external bandages (from the base of her feet) indicates that her linen wrappings were treated with a specific embalming "recipe" which is notably different from Kha's.

Kha's external wrappings were treated with an embalming "recipe" consisting of animal fat/plant oil mixed with a small amount of balsam/aromatic plant extract, a plant gum and a

conifer resin. The coniferous resin and the "balsam" gave the embalming "recipe" highly preservative—anti-bacterial and anti-insecticidal—properties [20,22,71]

Merit's embalming "recipe" consists largely of anunusual oil mixed with small amount of 'balsam', a conifer resin, beeswax and plant gum, providing at least some anti-bacterial protection. The presence of natron salt within Merit's outer wrappings confirms Merit's corpse was treated with what is regarded as the key ingredient of mummification, which again contradicts the presumed poor treatment afforded to her.

Conclusion

Both mummies were richly decorated with jewellery, and Kha additionally wears funerary amulets. Both probably also wear clothing. They were mummified with no removal of their internal organs (requiring no need of canopic equipment), including the brain, which remained inside the cranium.

The time and effort undoubtedly employed to embalm both Kha and Merit and the use of imported costly resins, notably Pistacia, do not support the view that the two notables were poorly mummified rather they provide the first evidence of an uncommon thanatological treatment applied to a mid-18th Dynasty wealthy couple.

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Author Contributions

Conceived and designed the experiments: RB MEH SB FJR. Performed the experiments: RB MEH SB RS LMO EV FJR. Analyzed the data: RB MEH SB JF RS LMO EV TB FJR. Wrote the paper: RB MEH SB JF RS LMO EV TB FJR.

References

1. Vassilika E. The Tomb of Kha. Firenze: Scala Group; 2010.
2. Schiaparelli E. La tomba intatta dell'architeto Cha. Relazione sui lavori della missione archeologica Italiano in Egitto (Anno 1902–1920). Turin; 1927.
3. Schiaparelli E, Roccati A, Fisher B. La tomba intatta dell'architetto Kha nella metropoli di Tebe-The intact tomb of the architect Kha in the necropolis of Thebes: 2. AdArte; 2008.
4. Ikram S, Dodson A. The Mummy in Ancient Egypt: Equipping the Dead for Eternity. London: Thames & Hudson; 1998.
5. Herodotus. The Histories. De Silincout A, editor. London: Penguin; 1954.
6. Diodorus Siculus. The Library of History. Oldfather CH, editor. London: Heinemann; 1935.
7. Strabo. The Geography. Jones HL, editor. London: Heinemann; 1932.
8. Pliny. Natural History. Rackham H, editor. London: Heinemann; 1968.
9. Smith GE. Tutankhamen and the Discovery of his Tomb. London: Routledge; 1923.
10. Smith GE. Egyptian Mummies. London: Allen & Unwin; 1924.
11. Cockburn A, Cockburn E, Reyman TA. Mummies, Disease and Ancient Cultures. Cambridge: Cambridge University Press; 1998.
12. Aufderheide AC. The Scientific Study of Mummies. Cambridge University Press; 2003.
13. Wade AD, Nelson AJ. Radiological evaluation of the evisceration tradition in ancient Egyptian mummies. Homo. 2013; 64: 1–28. doi: 10.1016/j.jchb.2012.11.005 PMID: 23290862

14. Sydler C, Öhrström LM, Woitek U, Rühli FJ. CT-based assessment of relative soft tissue alteration in different types of ancient mummies. Anat Rec (special mummy issue). 2015;
15. Rühli FJ. Magnetic Resonance Imaging of ancient mummies. Anat Rec (special mummy issue). 2015;
16. Öhrström LM, Fischer B, Bitzer A, Wallauer J, Walther M, Rühli FJ. Terahertz imaging modalities of ancient Egyptian mummified objects and a naturally mummified rat. Anat Rec (special mummy issue). 2015;
17. Colombini MP, Modugno F, Silvano F, Onor M. Characterization of the balm of an Egyptian mummy from the seventh century B.C. Stud Conserv. 2000; 45: 19–19.
18. Harrell JA, Lewan MD. Sources of mummy bitumen in ancient Egypt and Palestine. Archaeometry. 2002; 44: 285–293.
19. Koller J, Baumer U, Kaup Y, Etspüler H, Weser U. Embalming was used in Old Kingdom. Nature. 1998; 391: 343–344. PMID: 9450745
20. Buckley S, Evershed RP. Organic chemistry of embalming agents in Pharaonic and Graeco-Roman mummies. Nature. 2001; 413: 837–841. doi: 10.1038/35101588 PMID: 11677605
21. Buckley SA, Stott AW, Evershed RP. Studies of organic residues from ancient Egyptian mummies using high temperature-gas chromatography-mass spectrometry and sequential thermal desorption-gas chromatography-mass spectrometry and pyrolysis-gas chromatography-mass spectrometry. Analyst. 1999; 124: 443–452. PMID: 10605875
22. Koller J, Baumer U, Kaup Y, Schmid M, Weser U. Analysis of a pharaonic embalming tar. Nature. 2003; 425: 784. PMID: 14574400
23. Hornung E, Krauss R, Warburton DA, Seidelmeyer SJ, Verner M, Schneider T, et al. Ancient Egyptian chronology. Hornung E, Krauss R, Warburton DA, editors. Leiden: Brill; 2006.
24. Jones J, Higham TFG, Oldfield R, O'Connor TP, Stephen Buckley. Evidence for Prehistoric Origins of Egyptian Mummification in Late Neolithic Burials. PLOS One. 2014; 9: e103608. doi: 10.1371/journal.pone.0103608 PMID: 25118605
25. Peck WH. Mummies of ancient Egypt. In: Cockburn A, Cockburn E, Reyman TA, editors. Mummies, Disease and Ancient Cultures. Cambridge: Cambridge University Press; 1998. pp. 15–37.
26. Millet NB, Hart GD, Reyman TA, Zimmerman MR, Lewin PK. ROM I: mummification for the common people. In: Cockburn A, Cockburn E, Reyman TA, editors. Mummies, Disease and Ancient Cultures. Cambridge: Cambridge University Press; 1998. p. 91.105.
27. Saleem SN, Hawass Z. Variability in Brain Treatment During Mummification of Royal Egyptians Dated to the 18th–20th Dynasties: MDCT Findings Correlated With the Archaeologic Literature. Am J Roentgenol. 2013; 200: 336–344. doi: 10.2214/AJR.12.9405
28. Saleem SN, Hawass Z. Subcutaneous Packing in Royal Egyptian Mummies Dated From 18th to 20th Dynasties [online]. J Comput Assist Tomogr. 2015; doi: 10.1097/RCT.0000000000000205
29. Martina MC, Cesarani F, Boano R, Donadoni Roveri AM, Ferraris A, Grilletto R, et al. Kha and Merit: multidetector computed tomography and 3D reconstructions of two mummies from the Egyptian Museum of Turin. Journal of Biological Research Vol LXXX, N 1, Proceedings V World Congress on Mummy Studies. Rubbettino Editore; 2005. pp. 42–44.
30. Meskell L. Intimate archaeologies: the case of Kha and Merit. World Archaeol. 1998; 29: 363–379.
31. Meskell L. Archaeologies of Life and Death. Am J Archaeol. 1999; 103: 181–199.
32. Davis TM. The Tomb of Ioiya and Touiyou. London: Constable & Co.; 1907.
33. Curto S, Delorenzi E, Spagnotto D. I risultati d'una rilevazione radiografica e grafica su mummie. Oriens Antiq. 1980; 19: 147–157.
34. Delorenzi E, Grilletto R. Le Mummie Del Museo Egizio Di Turino N 13001–13026. Indagine anthropo-radiologica. Milano; 1989.
35. Curto S, Mancini M. News of Kha and Meryt. JEA. 1968; 54: 77–81.
36. Cesarini F, Martina MC, Boano R, Grilletto R, D'Amicone E, Venturi C, et al. Scenes from the Past. Multidetector CT Study of Gallbladder Stones in a Wrapped Egyptian Mummy. RandioGraphics. 2009; 29: 1191–1194.
37. (FDI). FDI. Two-digit system of designation of teeth. Int Dent J. 1971; 21: 104–106.
38. Trotter M, Gleser GC. Estimation of stature from long bones of American Whites and Negroes. Am J Phys Anthropol. 1952; 10: 463–514. doi: 10.1002/ajpa.1330100407 PMID: 13007782
39. Pearson K. Mathematical Contributions to the Theory of Evolution. V. On the Reconstruction of the Stature of Prehistoric Races. Philos Trans R Soc London Ser A, Contain Pap a Math or Phys Character. 1899; 192: 169–244. doi: 10.1098/rsta.1899.0004

40. Habicht ME, Henneberg M, Öhrström LM, Staub K, Rühli FJ. Body Height of Mummified Pharaohs Supports Historical Suggestions of Sibling Marriages [online]. Am J Phys Anthropol. 2015; doi: 10.1002/ajpa.22728
41. Melcher AH, Holowka S, Pharoah M, Lewin PK. Non-invasive computed tomography and three-dimensional reconstruction of the dentition of a 2,800-year-old Egyptian mummy exhibiting extensive dental disease. Am J Phys Anthropol. 1997; 103: 329–40. doi: 10.1002/(SICI)1096-8644(199707)103:3<329::AID-AJPA3>3.0.CO;2-L PMID: 9261496
42. Andrews C. Ancient Egyptian Jewellery. London: The Thrustees of the British Museum; 1990.
43. Vogelsang-Eastwood GM. Pharaonic Egyptian Clothing. Leiden, New York: E.J. Brill; 1993.
44. Rutica D, Habicht ME. Die Kleidung der Alten Ägypter. Kleidung, Perücken und Schmuck im pharaonischen Ägypten [in preparation]. 2015.
45. Watson PJ. Costume of Ancient Egypt. London: B.T. Batsford; 1987.
46. Müller HW, Thiem E. Die Schätze der Pharaonen. Augsburg: Battenberg; 1998.
47. Vernier É. Note Sur Les Boucles D'Oreilles Égyptiennes. BIFAO. 1911; 8: 15–41.
48. Binder S. The Gold of Honour in New Kingdom Egypt. Oxford: Aris & Phillips Ltd; 2008.
49. Stierlin H, Ziegler C. Tanis. Vergessene Schätze der Pharaonen. München: Hirmer Verlag; 1987.
50. Yoyotte J, Ziegler C, Leclant J, Vernus P. Tanis L'Or des Pharaons. Paris: Association Française d'Action Artistique; 1987.
51. Saleh M, Sourouzian H. Die Hauptwerke im Ägyptischen Museum Kairo. Mainz am Rhein: Philipp von Zabern; 1986.
52. Desroches-Noblecourt C, Duc M, Eggebrecht E, Hassanein F, Kurz M, Nelson M. Sen-nefer. Die Grabkammer des Bürgermeisters von Theben. Mainz: Philipp Von Zabern; 1986.
53. Davies N de G. The rock tombs of El Amarna. London: Off. of the Egypt Explor. Fund; 1903.
54. Martin GT. The hidden tombs of Memphis : new discoveries from the time of Tutankhamun and Ramesses the Great. London: Thames and Hudson; 1991.
55. Fletcher J. Ägypten—Leben und Sterben im Tal der Könige—(2/2)—Doku/Dokumentation. Deutschland / Frankreich (arte); 2014. Available: https://www.youtube.com/watch?v=DwhzuGZ9Nug
56. Reeves NC. The Complete Tutankhamun. The King. The Tomb. The Royal Treasure. London: Thames and Hudson Ltd; 1992.
57. Edwards IES. Tutanchamun. Das Grab und seine Schätze. GmbH GLV, editor. Bergisch Gladbach; 1978.
58. James TGH. Tutanchamun. Köln: Karl Müller Verlag; 2000.
59. Aldred C, Shoucair A. The jewels of the Pharaos: Egyptian jewellery of the dynastic period. London: London : Thames and Hudson; 1971.
60. Lilyquist C. The Tomb of Tuthmosis III's Foreign Wives. New York: Metropolitan Museum of Art; 2004.
61. Habicht ME. Gräber von Pharaonen und Königinnen des alten Ägypten, die noch zu finden sind. Unter dem Siegel der Nekropole. 2014; 1.
62. Winlock HE. The Treasure of Three Egyptian Princesses. New York: Metropolitan Museum of Art; 1948.
63. Fletcher J. The Search for Nefertiti. New York: William Morrow; 2004.
64. Gabolde M. L'ADN de la famille royale amarnienne et les source égyptiennes. Egypte Nilotique Méditeranéenne ENiM. 2013; 6: 177–203.
65. Habicht ME. Nofretete und Echnaton: Das Geheimnis der Amarna-Mumien. Leipzig: Koehler + Amelang Gmbh; 2011.
66. Saleh A. The Royal Mummies. Cairo: Middle East Co.; 2010.
67. Schlögl HA. Nofretete. Die Wahrheit über die schöne Königin. Beck C. H.; 2012.
68. Lucas A. Ancient Egyptian Materials and Industries. (rev. Harris J.R.), editor. London: Histories and Mysteries of Man; 1989.
69. Derry DE. Mummification II—methods practiced at different periods. ASAE. 1942; 41: 240–265.
70. Moiso B. Ernesto Schiaparelli e la Tomba di Kha. Turin: AdArte; 2008.
71. Buckley SA, Clark KA, Evershed RP. Complex organic chemical balms of Pharaonic animal mummies. Nature. 2004; 431: 294–9. doi: 10.1038/nature02849 PMID: 15372029

PLOS ONE

RESEARCH ARTICLE

Queen Nefertari, the Royal Spouse of Pharaoh Ramses II: A Multidisciplinary Investigation of the Mummified Remains Found in Her Tomb (QV66)

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Abstract

Queen Nefertari, the favourite Royal Consort of Pharaoh Ramses II (Ancient Egypt, New Kingdom, 19th Dynasty c. 1250 BC) is famous for her beautifully decorated tomb in the Valley of the Queens. Her burial was plundered in ancient times yet still many objects were found broken in the debris when the tomb was excavated. Amongst the found objects was a pair of mummified legs. They came to the Egyptian Museum in Turin and are henceforth regarded as the remains of this famous Queen, although they were never scientifically investigated. The following multidisciplinary investigation is the first ever performed on those remains. The results (radiocarbon dating, anthropology, paleopathology, genetics, chemistry and Egyptology) all strongly speak in favour of an identification of the remains as Nefertari's, although different explanations—albeit less likely—are considered and discussed. The legs probably belong to a lady, a fully adult individual, of about 40 years of age. The materials used for embalming are consistent with Ramesside mummification traditions and indeed all objects within the tomb robustly support the burial as of Queen Nefertari.

Introduction

The tomb of Queen Nefertari (QV 66), the second Great Royal Wife of King Ramses II (lifetime ca. 1303–1213 BC), was discovered by Ernesto Schiaparelli (1856–1928) in the Valley of the Queens in 1904. Her burial had been looted in antiquity, so no trace of the original entrance had been preserved. Besides the famous wall paintings, a series of broken remains

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(e.g. a damaged pink granite sarcophagus, broken furniture, jars, shabtis, other various small items), a pair of sandals and two fragmented mummified legs (parts of tibiae and femora) are preserved. All these items and the human remains are currently housed in the (Museo Egizio Turin, Suppl. 5154 RCGE 14467) [1–3]. (Table A in S1 File).

Nefertari was the most beloved wife of King Ramses II and played an active role in foreign politics. Her ancestry is unknown. Based on the legible/decipherable inscriptions on a fragment of a faience knob head or pommel found in her tomb, speculations were raised [4,5]. The item carries the throne name '*Kheper-Kheperu-Ra*' and, is, therefore, connected with King Ay [6], who ruled Egypt for a few years after Tutankhamun (Turin Mus. Egizio Inv. Suppl. 5162) [2,7]. However, Nefertari did not carry the title '*Daughter of a King*', which suggests that she was probably not from the main royal line. Because of the chronology, it seems quite unlikely that she was King Ay's daughter, perhaps she was Ay's grand-daughter [6,8] (Fig 1). Other scholars emphasize that both Ramses II's royal wives, Isisnofret [9] and Nefertari, had a non-royal background [10]. Nefertari married Ramses when he was crown prince during the reign of his father Sety I. The age at which Ramses II succeeded to the throne of Egypt is uncertain, possibly around his 25th year [10]. Nefertari was then presumably the same age as her husband or slightly younger (ca. 20–25 years). She gave birth to four sons (Amun-hir-khepeshef, Pa-Ra-wenem-ef, Mery-Ra and Mery-Atum) and four daughters (Baketmut, Nefertari, Merytamun and Henuttaui). Within the succession line, Nefertari's sons were always preferred to Queen Isisnofret's although, in the end, the crown went to Merenptah, a son of Queen Isisnofret. Queen Nefertari, as attested by reliefs, attended the opening ceremony of the rock-cut temples of Abu Simbel in the year 24 of Ramses II's reign (ca. 1255 BC) (Fig 2) [11]. After that event, she disappeared. She was absent at the Sed-festival of Ramses II's 30th regal year. She probably died around his 25th year of reign [10]. As reconstructed from historical records, Nefertari probably reached an age of about 40 to 50 years (minimum 16 + 24 years or maximum 25 + 25 years) whereas Queen Isisnofret I died later, in year 34. Subsequently Ramses II married three of his daughters: Bint-Anat, Merytamun and Nebettaui [10].

Aim

The aim of the research is to answer—via a multidisciplinary approach to a long historical debate–a complex question. Do the human remains found in the tomb belong to Queen Nefertari's original burial? (Fig 3). The remains of Nefertari are considered as highly important for History and Egyptology since Nefertari is one of the most famous Queens of Ancient Egypt.

Material

The human remains *Suppl. 5154 RCGE 14467* consist of three separate mummified human body parts: A long leg fragment consisting of a distal femur part, patella and a proximal tibia part (Fig 4); a medium sized part of an incomplete proximal tibia (Fig 5) and a short part of a femur (Fig 6).

Methods

Ethics statement

Ethic clearance was not needed, since the studied remains are older than 3200 years and no living relatives are known.

The permission to investigate was given by the Egyptian Museum in Turin by the director Eleni Vassilika. Permission to perform the radiocarbon dating was given by the new director Christian Greco.

Fig 1. Knob head or pommel with the throne name (Kheper-Kheperu-Ra) of King Ay. Museo Egizio Turin Suppl. 5162.

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a) Number of specimen: Three parts, probably belonging to one individual. Finding location: Egypt, Valley of the Queens, tomb QV 66 of Queen Nefertari.

b) The remains are on permanent, public display in Turin, Mus. Egizio. S. 05154 RCGE 14467.

c) A detailed permission was not needed.

d) No permits by ethics committee were required for the described study. All investigations were done according to our code of ethics:

IEM Code of Ethics http://www.iem.uzh.ch/en/institute/iemcodeofethics.html

Radiological assessment

The human remains were X-rayed *in situ* at Turin's Museum, using a portable, state-of-the-art mobile digital X-ray (EXAMION PX 60 HF; max. output 3.2 kW, Voltage range 40–100 kV, Exposure range 0.4–100 mAs).

Anthropometric reconstruction

To look for knee sizes, the condyle's width was compared to modern samples (young females Cape Coloured) and to ancient samples from Metapontum (Italy 700–300 BC) [12,13] (Table A in S1 File). Different body height formulae (for modern and for prehistoric remains) [14–16] were used to investigate the individual's stature. Comparison of the dimensions of QV 66 knees with those of modern poor Sub-Saharan African females was implemented [12].

Comparison of knees with ancient and modern samples

Proportionality rule was applied to compare the ancient samples with the knees from QV 66. Testing of z-score (165 cm– 158 cm) / SD 7 = +1 SD (the less favourable data of 3rd Intermediate Period) was implemented. By comparing the condyle's width to Cape Coloured data, sex

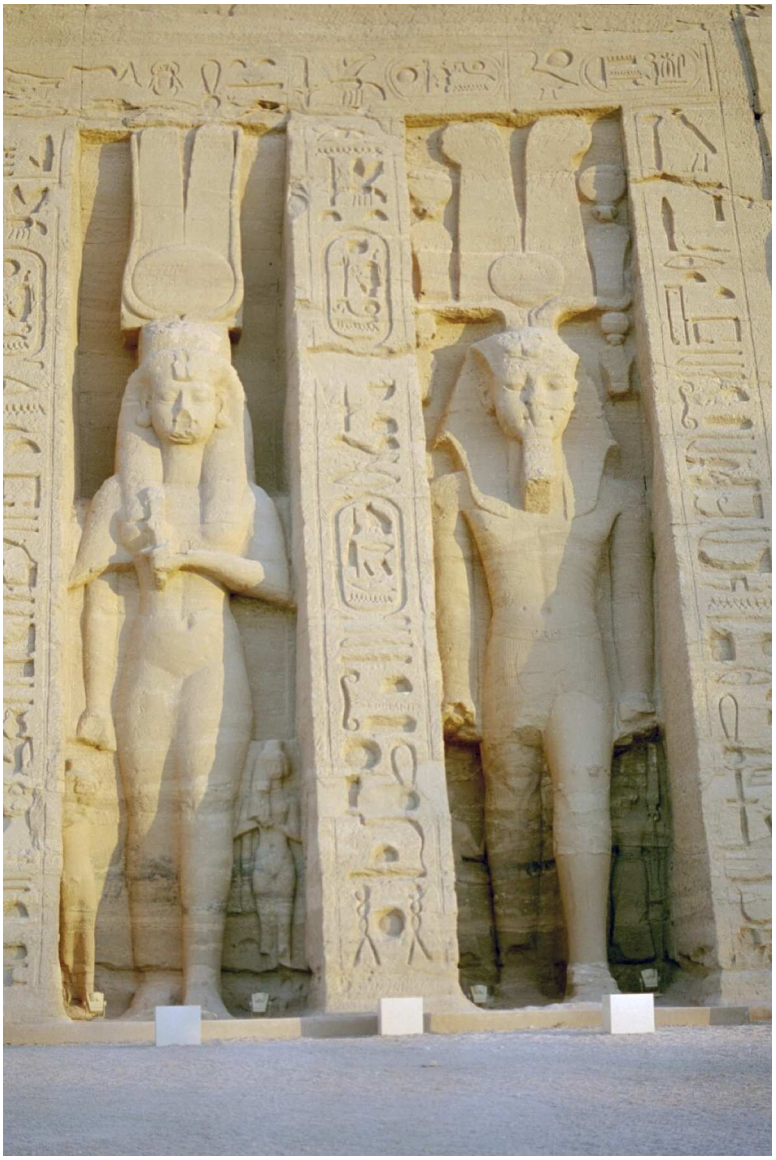

Fig 2. Abu Simbel, second rock temple dedicated to Nefertari, front: Nefertari's statue shows the same size as Ramses II in order to demonstrate her status and importance.

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dimorphism characteristics were tested (studies from ancient Egyptian samples being wanted). The size of the QV 66 knees was then assessed for sex determination via a measurement of both condyles on scaled X-ray pictures (Table A in S1 File).

Ancillary Egyptological analysis: the Sandals and Other Objects Found in Tomb QV 66

Sandals (also exhibited in the Turin museum) were found among other objects, such as the fragments of a stone sarcophagus of Nefertari bearing an inscription, 34 wooden shabtis bearing her name, two lids of coffers, fabric, broken pottery and fragments of wooden statues in Turin. Mus. Egizio (List B in S1 File). Almost all objects are either inscribed with the name of Nefertari or, at least, their styles link them to the 19th Dynasty. The objects were philologically

Fig 3. The mummified remains as shown in the 2014 exhibition in Museo Egizio Turin Suppl. 5154 RCGE 14467.

doi:10.1371/journal.pone.0166571.g003

Fig 4. Long leg fragment (No. 1).

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Fig 5. Medium sized part of tibia (Nr. 2).

doi:10.1371/journal.pone.0166571.g005

and epigraphically tested for consistency with the hypothesized time period and foot length can be used for forensic reconstruction of body height [17,18], using the regression equation for female [18] (87.906 + 3.165 x 24.5 = 165 cm).

Aside the obvious plundering of the tomb and its treasures there is no evidence for intended desecration of the Queen's body.

Valid for chemical analysis, DNA analysis and radiocarbon dating: Small skin, muscle and textile biopsies (1cm x 1cm) were taken for biochemical analysis (GC-MS), ancient DNA as well as radiocarbon dating investigations.

Chemical analysis

The amorphous organic residues impregnating the textile samples taken from the knee assemblage were chemically characterized and identified using gas chromatography (GC-MS). After initially grinding samples to a fine powder, a weighed amount of these ground samples (from

Fig 6. Short part of a femur (No. 3).

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10–90 mg) was taken. These samples were then extracted with an appropriate volume (0.5–2 mL) of chloroform-methanol solution (2:1 v/v; 3x60 min sonication). After centrifugation (20 min, 1000 rpm) the supernatant solvent was removed from the residue and placed in a vial. The three extracts were combined and the solvent reduced by rotary evaporation. Following transfer of the combined extracts to a screw-capped vial, the remaining solvent was removed by evaporation under a gentle stream of nitrogen at 40˚C. The residue was reweighed to give total lipid extracts (TLE). The TLEs were trimethylsilylated using N,O-bis(trimethylsilyl)trifluoroacetamide (Sigma-Aldrich Chemical Co., St Louis, MO, USA) containing 1% of trimethylchlorosilane (50 μl, 70˚C, 1 hour). Excess BSTFA was then removed under a gentle stream of nitrogen and the derivatized sample redissolved in dichloromethane and analyzed by GC-MS. GC-MS analysis of the total lipid extract of each sample was performed on a a Hewlett-Packard 5890 Series II gas chromatograph fitted with a split injector (325˚C) interfaced to a Trio 1000 mass spectrometer (electron voltage 70eV, filament current 200 uA, source temperature 170˚C, interface temperature 325˚C). The acquisition was controlled by Windows based MasSpecII32 Data System, in full scan mode (35–650 amu). Separation was performed on a fused silica capillary column (30 m x 0.25 mm i.d) coated with 0.25 um 5% phenyl methyl polysiloxane (DB-5). Initially the GC was held at 40˚C for 5 minutes and then temperature programmed from 40˚C-350˚C at 8˚C min and held at final temperature for 20 minutes (total time 63.75 minutes), with helium as the carrier gas (constant flow 1 ml/min, initial pressure of 45 kPa, splitless injection 1 min). Identification of compounds was achieved on the basis of both their mass spectra (NIST Mass Spectral Database and reference compounds) and relative retention times (relative retention indices (RRIs)).

DNA analysis

The analyses were performed at the dedicated ancient DNA laboratory at the Institute of Evolutionary Medicine of the University of Zurich. For genetic analysis the samples were cleaned using a 1% bleach solution to remove contaminating DNA from modern individuals that had handled the mummified remains and samples before air drying and crushed in a SPEX freezer mill (6770) to form a fine powder. The DNA was released from the bone powder by decalcification for 48 hours (12 hours 55˚C and 36 hours at room temperature) in a 0.45M EDTA (Ethylenediaminetetraacetic acid) solution with 100mg Proteinase K added to remove excess proteins and inhibit enzymatic activity. The DNA was released from the soft tissue using the extraction buffer (10mM Tris-HCl, 10mM NaCl, 5mM CaCl2, 2,5mM EDTA, 2% SDS, 40mM DTT and 100mg/ml Proteinase K) for 18 hours at 55˚C. The supernatant, containing released DNA, was then subjected to a Phenol-Chloroform extraction to remove any further proteins (mixed twice with 25:24:1, phenol:chloroform:isoamyl alcohol, and the DNA containing supernatants removed, final wash with chloroform), before being concentrated with a modified QiaQuick PCR purification method (final elution incubation at 37˚C for 5 minutes to maximise DNA yield). DNA extracts were subjected to conventional PCR amplification of the HVRI of the mtDNA D-loop with four overlapping primer sets and to a sexing assay using real-time PCR as previously described [19] Each extract was analyzed for mtDNA data twice and for sexing data three times, and three non-template extraction controls and reagent blanks were processed in parallel with each PCR.

Radiocarbon dating

Original sample of mummified tissue taken from the interior compartment of femura and tibiae contained 108 mg of material. A sample of 79.1 mg was taken for analysis and treated in a soxhlet system. A sequence of solvents (chloroform, hexane, acetone and ethanol) was used to

remove resins and waxes [20]. The remaining sample with a mass of 61.7 mg underwent modified acid base treatment [21]. The short treatment in room temperature (instead of 60C) was applied because the material underwent rapid dissolution. Only 20% (i.e. 13.5 mg) of the sample remained after ABA. The remaining material was weight into tin cups for a combustion Elemental Analyser and subsequent graphitization [22] two targets were prepared from the material: one contained mainly powder of the tissue and the second the remaining of the sample. These were then analysed using MICADAS, which is a dedicated ^{14}C AMS instrument at the AMS facility, ETH Zurich [23]. The measured ^{14}C content (F14C) was normalised to the standard Oxalic Acid 2 corrected for blank values and isotopic fractionation using delta ^{13}C measured on graphite see Hadjas 2008 [21]. Radiocarbon ages were calculated following the convention of Stuiver and Polach 1977 [24]. OxCal program [25] and INTCAL13 [26] data set were used to calibrate to calendar ages.

Results

Radiological assessment

The X-rays confirmed the presence of a pair of human knees, with distal part of femur, proximal part of tibia and fibular bone as well as the patella (Figs 7–10). It is sensible and a somewhat likely hypothesis that the remains actually belong to a single individual as also suggested by close visual inspection which, based on colour and texture, shows how the remains appear to be those of a single individual (Figs 3–6). This however cannot be proved with absolute certainty. The remains show massive, probably post mortem, multiple impacted fractures. While the femur does not show any fractures, the tibia on the contrary shows a fracture proximally and is multiply fractured at the distal end. The knee joint shows a narrowed joint space, a finding that is commonly observed in mummies and that does not necessarily imply underlying pathologies. The bandage layers can be differentiated on the X-rays. X-ray of the leg split in two separate parts show a right distal femur with multiple fractures (Fig 7) with surrounding soft tissue as well as bandage layers. This part is only fragmentarily preserved; only the metaphyseal parts of the left tibia and fibula are preserved (Fig 8). Surrounding soft tissue and bandage layers are visible. No prominent bone pathology (e.g. a tumorous lesion) could be spotted. The bone architecture is indeed generally normal (Figs 7–10). All epiphyses are fused, which implies that the remains belong to an adult individual. The X-rays revealed instead a very thin cortical thickness (ca. 1–2 mm) for which several differential interpretations may thus be given: minimal osteoathrosis, osteoporosis, vitamin D deficiency-caused osteomalacia (e.g. if the individual was secluded from sunlight), or disuse osteopaenia from cerebral palsy or other causes. If, in the absence of further clinical evidence, most of these pathologies are excluded and only minimal osteoarthrosis or osteopaenia are considered, then the eventuality that the individual underwent minimal physical labour as a consequence of a high status, characterised by predominantly indoor life can be proposed. No definitive solution however exists to this problem. In addition, in the left knee, it is possible to see what may be a calcification in the arteriae tibiales (anterior and posterior). This finding can be caused by arteriosclerosis or media calcinosis (Mönckeberg's sclerosis). Both differential diagnosis suggest an elderly person. Thus, we assume as one of the possibilities that the knees belonged to an individual older than 40 years. The accumulated evidence could point to an individual between 40 and 60 years old.

Anthropometric reconstruction

Both knee condyles show a ca. 83–85 mm width if mummified soft tissues are included and ca. 79–80 mm if only the bone is considered. A condyle width of ca 83–84 mm indicates that QV

Fig 7. X-ray; arranged as seen in Fig 3.

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66 knees were slightly slimmer than those of the younger and poorest women from Sub-Saharan Africa. There is no formula to re-calculate knee width from living to dead, only an estimate the greatest difference would be ca. 1.5 mm in knee width between living and dead persons [12,27,28]. Moreover, it was also possible to determine—acknowledging a certain degree of uncertainty—that the bones found in QV66 belonged to an individual whose stature ranged between 165 cm and 168 cm (Table A in S1 File).

Comparing knees with ancient and modern samples

Assessment of the size of the QV 66 knees revealed them to be female with a 90% likelihood. With a single exception, the knees from QV 66 belong to an individual taller than e.g. the average ancient Greek women's range (Table A in S1 File). From the size and proportion of the knees, the most likely body height of QV 66 female was determined to be 165 cm (+/- 2.5 cm). Compared with data about women from the New Kingdom (average 156 cm) and 3rd Intermediate Period (average 158 cm), she was taller than the average Egyptian woman [29]. The QV 66 female was approximately one Standard Deviation taller than average (or taller than 84% of the women of her time). The estimated height of ca. 165 cm is confirmed independently by the calculation of foot size and body height reconstruction obtained from the sandals found in the tomb, which, indeed, belonged to an individual of ca. 165 cm (see below). Compared to e.g. ancient Greek females QV 66 female is 95% above the ancient

Fig 8. Left: X-ray left knee; the arrow marks the minimal signs of arthritis. Right: lateral view; the arrow points to the calcification of the arteriae tibiales.

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Greek female range and close to the average male (she is equal in height to ancient Greek and Egyptian men) [13,29].

Ancillary Egyptological analysis: the Sandals and Other Objects Found in Tomb QV 66

Only the faience knob with the name of King Ay found in tomb QV 66 belongs to the late 18th Dynasty and predates Ramses II and Nefertari by perhaps two generations. The poor quality of

Fig 9. X-ray of right distal femur, pa.

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Fig 10. Fragments of left tibia and fibula; the arrow points to the calcification of the arteriae tibiales.

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the shabtis was also a matter of speculation as they seemed ill-fitting for a burial of a great Queen [8]. A fragment of a golden object with the name of Nefertari was discovered in 1988 when the tomb was restored [8]. Other fragments of jewellery without a provenance but bearing the name of the queen are also known. They may also come from QV 66 (List B in S1 File) [8].

The sandals are made of sewn fibre and they belong to the group of type C sandals (Veldmeijer´s classification): type C variation 1; the front strap is Type 3 and back strap is type 2 [30,31]. The style is typical of the 18th– 19th Dynasties [32,33]. The sandals from QV 66 show some wear caused by the movement of the foot on the dorsal (upper) side, the ventral side could not be studied due to mounting on a display panel (neither by Veldmeijer, nor by the authors of the present study). The sandals measure 29 cm in length and 10 cm in width (Fig 11). Type C has a pointed, slightly upturned toe pointing to a modern shoe size of 39–40, if one only counts the length used by the foot, indicated by the imprints and the subtraction of the pointed end [34]. Furthermore the model clearly indicates the position of the big toe, with visible marks of the size, especially on the left sandal: It can be deduced, with a certain reservation, that the sandals' owner had a body height ranging c. 165 cm using forensic methods [17]. Veldmeijer described the sandals as those of Queen Nefertari [30]. The fine quality manufacture and high quality of the sandals speaks in favour of royal footwear. Thus it is widely accepted, that all objects found in QV 66 seem to be part of the original burial of Queen Nefertari, broken by ancient tomb robbers [7].

Chemical analysis (data on embalming agents)

The results of the chemistry of the embalming agents suggest a date earlier than the 3rd Intermediate Period, which is consistent with the evidence for the mummification materials and methods detailed below: the absence of bitumen is consistent with a New Kingdom date since it does not appear in balms from mummies until 900 BC [35,36]. The use of bitumen, and more liberal employment of tree resins in the embalming recipes, is seen in 3rd Intermediate Period mummies and later, the use and proportion of both in relation to the plant oil/animal fat base increasing over time with greatest use during the Ptolemaic and Roman Periods [35,37–39]. Bitumen was not detected in any of the samples from the knee assemblage despite selectively

Fig 11. Sandals from tomb QV 66. Museo Egizio Turin Suppl. 5160 RCGE 14471.

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monitoring for the presence of hopanes (m/z 191) and steranes (m/z 217) characteristic of a true natural bitumen [40]; Constituents of coniferous and non-coniferous resins were also not detected. The biomarkers for both these natural products are highly resilient and so can be expected to survive in a burial environment such as QV66 if they were originally present (Fig 12). This is consistent with these samples being largely from the outer layers of wrappings where oils or fats are usually the main or only 'embalming agent' during the New Kingdom, and are used to convey religious, political and cultural identities at this time [37]. In this context, it is notable that the samples from the mummified knees all revealed a non-human animal fat as the source of the embalming agents applied liberally to their linen wrappings, with all parts of the knee 'assemblage' showing a very similar lipid (fat) profile suggesting a likely common origin, i.e. the same individual. The same non-human animal fat, most likely a ruminant fat, constituting the embalming agent in the outer wrappings from all three parts of the knee assemblage, combined with the absence of evidence for a natron bath being employed and other aspects of the mummification, suggest a 19th or 20th Dynasty date for the mummification. Massive subcutaneous stuffing, the characteristic of the 3rd Intermediate Period, is not visible.

DNA analysis

Mitochondrial sequences were only obtained from Primer Set 3, and only from the left fibula (bone) and the upper right (bone and soft tissue) samples. All samples showed multiple mtDNA sequences, with the soft and bone tissue from the upper right sampling area showing different sequences from each other. This indicated that there are at least two contamination events in these samples. The sexing assay showed a weak amplification of the X-chromosomal target in the left fibula bone sample (twice) and the left femur soft tissue sample (once), and one strong signal in the upper right soft tissue sample. The clear evidence of allelic drop-out, together with the evidence of contamination from the mtDNA data, means that no conclusions can be drawn on these data. The inappropriate genetic behaviour exhibited in these samples (for example, strong amplification of nuclear DNA with no mtDNA amplification as seen in the upper right soft tissue sample) is further evidence that these samples are not suitable for further DNA analysis.

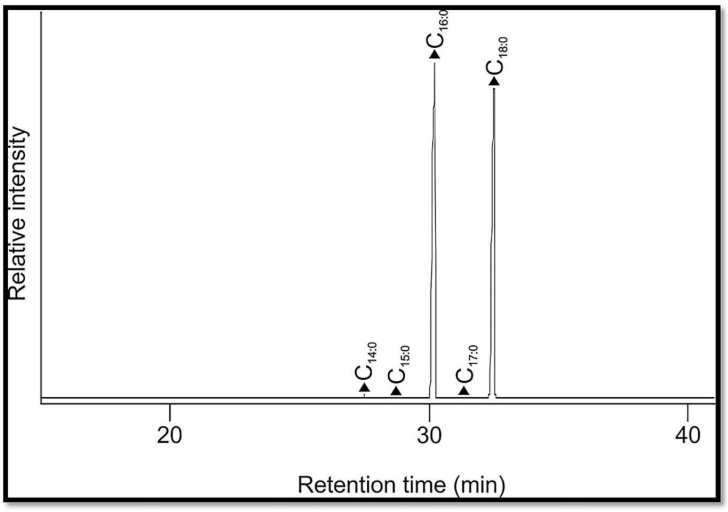

Fig 12. Reconstructed gas chromatography-mass spectrometry (GC-MS) total ion chromatogram (TIC) of the trimethylsilylated total lipid extract of 'resin'/linen wrapping from left long leg fragment. Peak identities ('n' indicates carbon chain length; where shown, i indicates degree of unsaturation): filled triangles, $C_{n:i}$ indicates fatty acids.

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Radiocarbon dating

The radiocarbon ages obtained on the 2 targets are in a very close agreement (ETH-67019.1: 3261±24 BP; ETH-67019.2: 3227±24 BP). The combined age of the sample is 3244±17 BP, X2-Test: df = 1 T = 1.0(5% 3.8). The calibration of this combined radiocarbon age results in a wide range of calendar ages. In some cases due to the shape of the calibration curve in the region of interest, the age of the sample falls into a period, where more precise information about the true age cannot be given [20]. Such is the case of this sample (Fig 13) and all the intervals between 1607BC and 1450 BC (95.4% conf. level) has to be considered.

OxCal v4.2.4 [25]; r:5. IntCal13 atmospheric curve [26]

ETH-67019 R_Combine (3244,17)

68.2% probability	1531BC (65.1%) 1497BC
	1469BC (3.1%) 1465BC
95.4% probability	1607BC (9.3%) 1582BC
	1561BC (1.2%) 1553BC
	1546BC (69.0%) 1491BC
	1485BC (15.8%) 1450BC

All results fall in the time of the late 2nd Intermediate Period and the New Kingdom (Fig 13).

Discussion of the Different Hypotheses

The objects and human remains found in tomb QV 66 provide us with information which allows a contextualization of the findings and to access to their likelihood.

Discussion on the radiocarbon dating of the remains

The obtained radiocarbon age is older than historic date of the tomb QV 66 but a discrepancy between ^{14}C based chronology and Egyptian calendar has been debated ever since Minoan Eruption of Thera was dated by ^{14}C (ranging 2σ 1663–1599 B.C.) [41,42]. In addition, fish diet could have possible effect on the ^{14}C age of the tissue as discussed in the study of mummified Ibis [43]. Such discrepancies between ^{14}C dates and assumed chronological models are observable for several time periods [44]. The results appear slightly older than the assumed lifespan of Queen Nefertari (early 19th Dynasty). The potential contamination

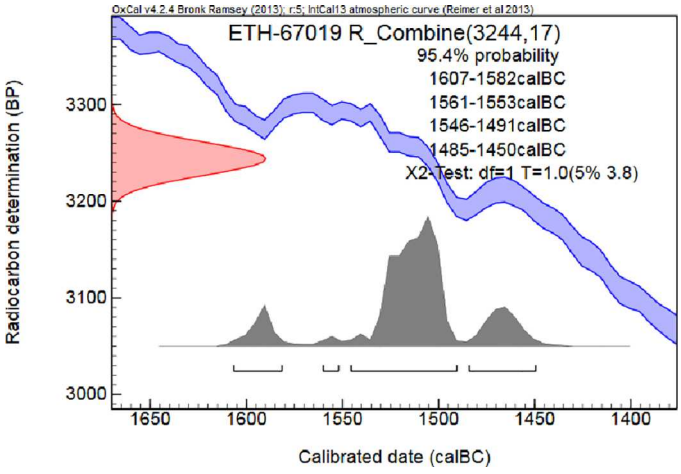

Fig 13. Calibrated result of the radiocarbon dating.

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sources could be older embalming agents used for mummification as well as intruding sediment during the recorded several mudslides in antiquity [8]. Such potential contamination would make the sample appear older. Although the old (stored) conservation agents cannot be excluded the treatment of samples removed potential contamination with carbonates and humic acids, which could originate from sediments. Furthermore, the geography of the valley and the location of tomb QV 66 make it unrealistic that older remains were washed in uphill. Rather a later dating of the remains in QV 66 would be problematic for identification as Nefertari.

Hypothesis 1: The mummified legs belong to Queen Nefertari

Reconstruction is based on ancient Egyptian funerary customs and recorded evidence found in QV 66. Nefertari died aged 40 to 50 years after the 24th year of Ramses II's reign and was embalmed. Her mummy was decorated with funerary jewellery bearing her name as the deified Osiris (Boston, Museum of Fine Arts Inv. 04.1954, Inv. 04.1955, Inv. 04.1956). Her mummy was placed in gilded wooden coffins (splinters were found in QV 66). The coffins were placed in a stone sarcophagus (Turin, Mus. Egizio S. 5153 RCGE 17494) bearing her name. The niches in the burial chamber were equipped with magical bricks (Turin Mus. Egizio S. 5163 RCGE 14473). Statues of Gods made of black-coated wood were placed in her tomb (Turin Mus. Egizio S. 5202 RCGE 14477) along with other funerary goods, some of which bear her name (coffers: Turin Mus. Egizio S. 5198, RCGE 14474, S. 5199 RCGE 14475). The reason why the faience knob or pommel inscribed with Kheper-Kheperu-Ra's (= King Ay) name was found in QV 66 remains a mystery. It is possible that Nefertari was a surviving descendant of the 18th Dynasty royal family. The tomb robbers smashed the stone sarcophagus, pulled the coffins out and ripped the mummy into pieces. The remains were thrown on the ground; the funerary equipment was plundered and only the wooden, clay and stone objects were left behind. Some of the funerary jewellery was lost during the looting. Later water intrusions badly damaged the tomb leaving a layer of debris over the objects. The basic anatomical observations and the mummification methods and materials are consistent with a high status burial from the 19th Dynasty.

Hypothesis 2: The remains Nefertari and one of her daughters

Following a second hypothesis, the tomb looters took away all objects belonging to Nefertari´s children and only those of Nefertari remained in the debris. The tomb robbers smashed the stone sarcophagus, pulled the coffins out and ripped the mummies of Nefertari and her children into pieces. As a matter of fact some of Nefertari´s daughters were buried in their own tombs in the Valley of the Queens: Merytamun in QV68 (her broken sarcophagus is preserved in Berlin) and Nebettaui in QV60. Even if one of her daughters, Baketmut or/and Henuttaui may have been buried at the side of their mother, there is no archaeological indication of an additional burial in QV 66. The likelihood of this hypothesis is considerably low.

Hypothesis 3: A secondary burial

The radiocarbon dating, chemistry and archaeology rule out a later burial in the 3rd Intermediate or Late Period entirely.

Hypothesis 4: The remains are washed in from an earlier burial

The results from the radiocarbon dating offer the possibility that remains from a burial of the 17th or 18th Dynasty were washed in the tomb after it was open. Archaeological material

found does not support such a hypothesis (e.g. material from other time periods and inscriptions naming other individuals). Tomb QV 66 is on higher ground at the side of the Valley of the Queens, while the burials from the 17th and 18th Dynasty are on lower ground, mostly at the bottom of the valley. Mudslide and heavy rains would have washed remains out of the valley but unlikely upwards and towards the end of the valley.

Conclusion

The first hypothesis seems to be the most credible and realistic and is coherent with the findings of the excavators and with the inscriptions found on the funerary objects. Thus, the most likely scenario is that the mummified knees truly belong to Queen Nefertari. Although this identification is highly likely, no absolute certainty exists. A list of default criteria was made to test the likelihood of the first hypothesis (Table 1). Certain default criteria were not found, which would exclude the identification of the knees as those of Queen Nefertari (default criteria by chemistry or aDNA with reservation). The fitting criteria are in the majority (Table 1).

Table 1. Likelihood (default criteria to exclude Nefertari).

Question	Result	Requirements for Nefertari	Fitting Inconclusive or Default
Genetic sex test	undefined, no Y-chromosome found	Female	Inconclusive
Anthropometric reconstruction	Tall female, very slim	female, perhaps tall, as she is usually represented in the Ramesside art	Fitting
Genetic profile		No genetic data from Ramses II or her children available (may remain inconclusive for the time being)	Inconclusive
Radiocarbon dating	New Kingdom, c. 3447 BP	Minimum 3200 BPA dating later than 19thDynasty would point to a secondary burial (default)	Older than expected, not a default
Age assessment	Adult 40–50 years	40 to 50 years	Fitting
Chemistry of the embalming agents	Chemistry of all parts is the same. They belong most likelyto one individual. Thechemistry suggests New Kingdom and 19-20th Dynasty	Should be New Kingdom and royal. No use of Bitumen.	Fitting
Mummification style	No natron bath, no stuffing,Dry natron, royal quality	No natron bath, no stuffing visible, good quality	Fitting
Archaeology	Tomb broken in antiquity	No indication of a burial post-dating the Ramesside Dynasty	Fitting
Sarcophagus	Name of Nefertari inscribed	19th Dynasty Sarcophagus	Fitting
Magic bricks	Made for Nefertari, her name is inscribed	Made for Nefertari	Fitting
Shabtis	Made for Nefertari, her name is inscribed	Made for Nefertari	Fitting
Jewellery	Funerary jewellery with her name inscribed	Jewellery of royal quality, with her name inscribed. Funerary jewellery	Fitting
Furniture	Made for Nefertari, her name is inscribed	Made for Nefertari	Fitting
Wooden black statues	Wepwawet or Anubis	Typical funerary statues in royal burials	Fitting
Sandal	Size 39, Type Veldmeijer C Var. 1 (later 18th to 19th Dynasty) [30]	Footwear in style of 19th Dyn.	Fitting
Pommel (of Sceptre or furniture)	Name of King Ay	No object is later than the time of Ramses II	Fitting

From 16 criteria are 14 classified as fitting and 2 as inconclusive. A certain default was not found.

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Supporting Information

S1 File. Habicht et al. Nefertari Supplementary Material Online PLOSone.pdf.

- **Table A in S1 File: Ancient Greek anthropometric data** (Metapontum, Henneberg and Henneberg, 1998) with subsequent proportional calculations of body height as for QV 66.
- **List B in S1 File: Objects from tomb QV 66** now in Turin, Mus. Egizio and Boston, Mus. of Fine Arts.
(DOCX)

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References

1. Schiaparelli E. Inventario manoscritto. 1904.
2. Vassilika E. Masterpieces of the Museo Egizio in Turin. Firenze: Scala Group; 2012.
3. Grilletto R. Materiali antropologici e zoologici provenienti dall'Egitto e conservati nel Museo Egizio di Torino e nel Museo di Anthropologia dell' Università di Torino, consistenza e collocazione al 1991. Torino; 1991.
4. Dodson A, Hilton D. The Complete Royal Families of Ancient Egypt. Thames & Hudson; 2004.
5. Leblanc C, Siliotti A. Nefertari e la Valle delle Regine. Florence: Giunti; 1993.
6. Hari R. Mout-Nefertari, épouse de Ramsès II: Une descendante de l'héretique Ai? Aegyptus. 1979; 59: 3–7.
7. McDonald JK. House of eternity: the tomb of Nefertari. Cairo: The American University in Cairo Press; 1996.

8. Willeitner J, Schmidt HC. Nefertari. Gemahlin Ramses II. Mainz: Philipp Von Zabern; 1997.
9. Leblanc C. Isis-Nofret, grande épouse de Ramsès II. Quelques reflexions sur la reine, sa famille et Nofretari. BIFAO. 1993; 93: 313–333.
10. Schlögl HA. Ramses II. 3rd ed. Reinbeck bei Hamburg: Rowohlt; 2000.
11. Willeitner J. Abu Simbel: die Felsentempel Ramses' II. von der Pharaonenzeit bis heute. Mainz am Rhein: Verlag Philipp von Zabern; 2010.
12. Henneberg M, Louw GJ. Average menarcheal age of higher socioeconomic status urban Cape coloured girls assessed by means of status quo and recall methods. Am J Phys Anthropol. 1995; 96: 1–5. doi: 10.1002/ajpa.1330960102 PMID: 7726292
13. Henneberg M, Henneberg RJ. Biological Characteristics of the Population Based on Analysis of Skeletal Remains. In: Carter JC, Morter J, Toxey AP, editors. The Chora of Metaponto The Necropoleis Volume II. Austin, TX: University of Texas Press; 1998. pp. 503–556.
14. Trotter M, Gleser GC. A re-evaluation of stature based on measurements of stature taken during life and of long bones after death. Am Journ Phys Anthropol. 1958; 16: 79–123.
15. Trotter M, Gleser GC. Corrigenda to 'estimation of stature from long limb bones of American Whites and Negroes,' American Journal Physical Anthropology (1952). Am J Phys Anthropol. 1977; 47: 355–356. doi: 10.1002/ajpa.1330470216 PMID: 910890
16. Pearson K. Mathematical Contributions to the Theory of Evolution. V. On the Reconstruction of the Stature of Prehistoric Races. Philos Trans R Soc London Ser A, Contain Pap a Math or Phys Character. 1899; 192: 169–244. doi: 10.1098/rsta.1899.0004
17. Krishan K, Kanchan T. Foot length is a functional parameter for assessment of height. Foot (Edinb). 2013; 23: 54–5. doi: 10.1016/j.foot.2012.12.002 PMID: 23414623
18. Pawar RM, Pawar MN. 'Foot length—A functional parameter for assessment of height'. Foot (Edinb). 2012; 22: 31–4. doi: 10.1016/j.foot.2011.10.002 PMID: 22280993
19. Krüttli A, Bouwman A, Akgül G, Della Casa P, Rühli FJ, Warinner C. Ancient DNA analysis reveals high frequency of European lactase persistence allele (T-13910) in medieval central europe. PLoS One. 2014; 9: e86251. doi: 10.1371/journal.pone.0086251 PMID: 24465990
20. Hajdas I. Radiocarbon: Calibration to Absolute Time Scale. In: Turekian K, Holland H, editors. Treatise on Geochemistry. 2nd ed. Oxford: Elsevier; 2014. pp. 37–43.
21. Hajdas I. Radiocarbon dating and its applications in Quaternary studies. Eiszeitalter und Gegenwart Quat Sci J. 2008; 57.
22. Wacker L, Nemec M, Bourquin J. A revolutionary graphitisation system: Fully automated, compact and simple. Nucl Instruments Methods Phys Res Sect B-Beam Interact with Mater Atoms. 2010; 268: 931–934.
23. Synal HA, Stocker M, Suter M. MICADAS: A new compact radiocarbon AMS system. Nucl Instruments Methods Phys Res Sect B-Beam Interact with Mater Atoms. 2007; 259: 7–13.
24. Stuiver M, Polach HH. Reporting 14C data. Radiocarbon. 1977; 19: 355–363.
25. Bronk Ramsey C., Scott M, van der Plicht H. Calibration for Archaeological and Environmental Terrestrial Samples in the Time Range 26–50 ka cal BP. Radiocarbon. 2013; 55: 2021–2027. Available: http://www.rug.nl/research/portal/files/2341905/2013RadiocarbonBronkRamsey.pdf
26. Reimer PJ, Bard E, Bayliss A, Beck JW, Blackwell PG, Bronk Ramsey C, et al. IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0–50,000 Years cal BP. Radiocarbon. 2013; 55.
27. Henneberg M, Louw GJ. Cross-sectional Survey of Growth of Urban and Rural '"Cape Coloured"' School children: Anthropometry and Functional Tests. Am J Phys Anthropol. 1998; 10: 73–85.
28. Siddiqi N. Comparison of osteometric femoral bone dimensions among the South Africans of different ethnic groups and South African whites. Egypt J Forensic Sci. 2013; 3: 8–14.
29. Habicht ME, Henneberg M, Öhrström LM, Staub K, Rühli FJ. Body Height of Mummified Pharaohs Supports Historical Suggestions of Sibling Marriages [online]. Am J Phys Anthropol. 2015; doi: 10.1002/ajpa.22728 PMID: 25916977
30. Veldmeijer AJ, Clapham AJ. Tutankhamun's footwear: studies of ancient Egyptian footwear. Leiden: Sidestone Press; 2011.
31. Veldmeijer AJ. Studies of Ancient Egyptian Footwear. Technological Aspects. Part VI. Sewn Sandals. In: Ikram S, Dodson A, editors. Beyond the Horizon Studies in Egyptian Art, Archaeology and History in Honour of Barry J Kemp. Cairo: The Supreme Council of Antiquities; 2009. pp. 554–580.
32. Zoffili E. Kleidung und Schmuck im Alten Ägypten. Frankfurt am Main: Propyläen Verlag; 1992.
33. Vogelsang-Eastwood GM. Die Kleider des Pharaos. Die Verwendung von Stoffen im Alten Ägypten. Hannover: Kestner-Museum; 1995.

34. Convert World: Shoe size. In: Convert World [Internet]. 2014. Available: http://www.convertworld.com/en/shoe-size/

35. Harrell JA, Lewan MD. Sources of mummy bitumen in ancient Egypt and Palestine. Archaeometry. 2002; 44: 285–293.

36. Buckley SA, Nissenbaum A. Dead sea asphalt in ancient egyptian mummies-why? Archaeometry. 2013; 55: 563–568. doi: 10.1111/j.1475-4754.2012.00713.x

37. Buckley S, Evershed RP. Organic chemistry of embalming agents in Pharaonic and Graeco-Roman mummies. Nature. 2001; 413: 837–841. doi: 10.1038/35101588 PMID: 11677605

38. Colombini MP, Modugno F, Silvano F, Onor M. Characterization of the balm of an Egyptian mummy from the seventh century B.C. Stud Conserv. 2000; 45: 19–29.

39. Connan J. Le bitume des momies Égyptiennes, un passport pour l'éternité. Recherche. 1991; 238: 1503–1504.

40. Rullkötter J, Nissenbaum A. Dead Sea asphalt in Egyptian mummies: molecular evidence. Naturwissenschaften. 1988; 75: 618–621. PMID: 3237249

41. Friedrich WL, Kromer B, Friedrich M, Heinemeier J, Pfeiffer T, Talamo S. Santorini Eruption Radiocarbon Dated to 1627–1600 B.C. Science (80-). 2006; 312: 548. doi: 10.1126/science.1125087 PMID: 16645088

42. Bietak M. Science Versus Archaeology: Problems and Consequences of High Aegean Chronology. The Synchronisation of Civilisations in the Eastern Mediterranean in the Mid Second Millenium. Wien: Oxbow Books; 2003. pp. 22–33.

43. Wasef S, Wood R, El Merghani S, Ikram S, Curtis C, Holland B, et al. Radiocarbon dating of Sacred Ibis mummies from ancient Egypt. J Archaeol Sci. 2015; 4: 355–361. doi: 10.1016/j.jasrep.2015.09.020

44. Gautschy R, Habicht ME, Galassi FM, Rutica D, Hannig R, Rühli FJ. A new astronomically based chronological model for the Egyptian Old Kingdom [submitted]. 2016;

Queen Nefertari, the Royal Spouse of Pharaoh Ramses II: A Multidisciplinary Investigation of the Mummified Remains Found in Her Tomb (QV66)

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Supplementary Material

A: Ancient Greek anthropometric data (Metapontum, Henneberg and Henneberg, 1998) with subsequent proportional calculations of body height as for QV 66.

Sample	**Condyle width (one, both sides)**	**Femur length**	**Tibia length**	**height (Trotter Gleser female white)**	**Corrected for QV 66**	**Height (Trotter Gleser female black African)**	**Corrected for QV 66**	**Height (Pearson 1899 female)**	**Corrected for QV 66**
Female	77 mm	410 mm	326 mm	155.5 cm	156.5 cm	155.74 cm (femur) 156.1 cm (tibia)	161.8 cm	152.0 cm	157.9 cm
Female tomb 99	68 and 69 mm	409 mm	354 mm	155.4 cm	181.5 cm	155.5 cm (femur) 163.0 cm (tibia)	181.6 cm	155.1 cm	181.0 cm
Female tomb 100	80 mm	452 mm	No data	165.7 cm	165.7 cm (no correction 1:1)	165.3 (femur)	165.3 cm	160.8 cm	160.8 cm
Female	70 mm	No data	343 mm	161 cm	162.1 cm	160.3 cm (tibia)	171.8 cm	155.4 cm	166.6 cm
Female	72 and 74 at femur head 70 and 70 at tibia head	393 and 394 mm	330 mm both	153.8 cm	168.5 cm	151.9 cm (femur) 157.1 (tibia)	166.4 cm 168.3 cm	150.6 cm	165.1 cm
Female	75 mm femur heads 71	427 mm	354 and 352 mm	161.6 cm	Femur 172.4 cm Tibia	159.6 cm (femur) 162.8 cm	170.3 cm171.9 cm	157.0 cm	167.4 cm

	tibia heads				170.7 cm	(tibia)			

B: Objects from tomb QV 66 now in Turin, Mus. Egizio and Boston, Mus. of Fine Arts:

1. Sandals, fibre, 29 x 10 cm, Mus. Egizio S. 5160 RCGE 14471. Sewn sandals, Veldmeijer Type C, var. 1 [1].
2. Djed-Amulet, 13 cm, Mus. Egizio S. 5163 RCGE 14473. It is a magical brick, placed in a niche as magic protection of the burial. This burial object is a strong argument for a burial of Queen Nefertari in QV 66.
3. Fragment of Djed-Amulet, 15 cm, Mus. Egizio S. 5204 RCGE 14479.
4. Fragments of a stone sarcophagus with inscription, 40 x 110 x 265 cm, pink granite, Mus. Egizio S. 5153 RCGE 17494.
5. Lid of a black coffer, 26 x 19 cm, with inscription and name of Nefertari, sycamore wood, Mus. Egizio S. 5198, RCGE 14474.
6. Lid of a coloured coffer, 13.5 x 9.5 cm, with inscription and name of Nefertari, sycamore wood, Mus. Egizio S. 5199 RCGE 14475.
7. Fragments of a rope, fibre, Mus. Egizio S. 5157 RCGE 14469.
8. Fragments of fabric, fibre, Mus. Egizio S. 5256 RCGE 14468.
9. Fragment of a vase, calcite, Mus. Egizio S. 5211 RCGE 14481.
10. Mummified remains, three parts of knees, Mus. Egizio S. 5154 RCGE 14467.
11. Pommel of a sceptre or a coffer knob, faience. Cartouche Kheper-Kheperu-Ra (King Ay), Mus. Egizio S. 5162 RCGE 14472. Late 18th Dynasty.
12. 34 shabtis, sycamore wood and bitumen, with inscription and name of Nefertari, Mus. Egizio S. 5164- 5197 all: RCGE 13509.
13. Fragment of a wooden statue, 32 cm, Mus. Egizio S. 5202 RCGE 14477. Probably the tail of an Anubis- or Wepwawet-statue, similar to the statue found in Tutankhamun´s tomb (Cairo JE 61444, Carter No. 261)
14. Fragment of a wooden statue of an Ibis, 25 cm, Mus. Egizio S. 5201 RCGE 14477. Similar statues of Thoth as an ibis are known from Horemheb and other Kings.

15. 4 fragments of blue glazed vases, Mus. Egizio S. 5210, RCGE 14481. The style of ceramic points to the 19th Dynasty.
16. Jar, clay, Mus. Egizio S. 5206 RCGE 13507. The style points to the New Kingdom.

Other shabtis from QV 66 are kept in Toronto and Cairo and Boston. Albert M. Lithgoe acquired for the Museum of Fine Arts three fragments of jewellery and shabtis, allegedly from her tomb in 1904 [2].

- Shabti, Boston, Museum of Fine Arts Inv. 04.1766
- Shabti, Boston, Museum of Fine Arts Inv. 04.1767
- Shabti, Boston, Museum of Fine Arts Inv. 04.1768
- Shabti, Boston, Museum of Fine Arts Inv. 04.1769
- Part of a gold bracelet of Nefertari, Boston, Museum of Fine Arts Inv. 04.1954. The inscription "Great royal wife, Nefertari-beloved-of-Mut, justified" points to a jewel specially made for the funeral.
- Part of a gold bracelet of Nefertari, Boston, Museum of Fine Arts Inv. 04.1955. The inscription describes Nefertari as "Osiris", thus it was also specially made for the funeral.
- Gilded Lotus ear-ring, Boston, Museum of Fine Arts Inv. 04.1956. Similar earrings are seen on the wall paintings in tomb QV 66 depicting Queen Nefertari.

Another object might also came from QV 66:

- Ivory Unguent Box with cartouches of Ramses II and Nefertari, 3 cm high, 5 cm diameter. New York, Metropolitan Museum, Inv. 26.7.1291. Acquired in 1926 [2]

Supplement references

1. Veldmeijer AJ. Studies of Ancient Egyptian Footwear. Technological Aspects. Part VI. Sewn Sandals. In: Ikram S, Dodson A, editors. Beyond the Horizon Studies in Egyptian Art, Archaeology and History in Honour of Barry J Kemp. Cairo: The Supreme Council of Antiquities; 2009. pp. 554–580.
2. Willeitner J, Schmidt HC. Nefertari. Gemahlin Ramses II. Mainz: Philipp Von Zabern; 1997.

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Oldest case of gigantism? Assessment of the alleged remains of Sa-Nakht, king of ancient Egypt

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Gigantism and acromegaly are endocrinological conditions of the greatest antiquity.
While mythology and literature abounds with descriptions of giants, the oldest reported palaeopathological cases are remains of a person with acromegaly from 9500 to 11 500 years ago found in New Mexico, USA, and remains of a giant with signs of acromegaly from ancient Egypt (Giza; c 2425 BCE [5th Dynasty]). In 1901, a skeleton was found in the Mastaba K2 tomb near Beit Khallaf, Egypt, which is estimated to date from the 3rd Dynasty (c 2700 BCE). The remains are of a very tall man (about 187 cm; figure) and are attributed to King Sa-Nakht, who was an ephemeral king of Egypt during the 3rd Dynasty. It is far from certain whether the remains are really those of King Sa-Nakht, but for the medical assessment of potential gigantism this case has a great value as it could be the oldest known case. The original reports of when the skeleton was found in 1901 gave no definitive diagnosis of either acromegaly or gigantism—both conditions having then already been described in the medical literature—although the case is described several times in general terms in the endocrinological literature.

A Unique Case of Stroke and Upper Limb Paralysis in a Mid-18th Century Natural Mummy

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Introduction

Despite its globally acknowledged importance in the clinical setting, the history of stroke has to date only been reconstructed through historical descriptions, whereas no clear palaeopathological evidence has ever been adduced. Here, a unique case of a naturally mummified body from the mid-18th century is shown to have a high degree of contracture of the upper left hand, whereas coeval documentary sources clearly indicate that the patient experienced a stroke in the last phase of his life that left him disabled. This example highlights how a combination of historical research and traditional palaeopathology can help in the reassessment of the presence of cerebrovascular diseases in the past.

HomeCirculation ResearchVol. 121, No. 4A Unique Case of Stroke and Upper Limb Paralysis in a Mid-18th Century Natural Mummy

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Poliomyelitis in Ancient Egypt?

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Letter to the Editor

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Keywords

Cane Congenital Malformation Clubfoot Poliomyelitis National Museum
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Although asymptomatic in 95 % of cases, in 1 % of them poliomyelitis involves the central nervous system resulting in muscular weakness and acute flaccid paralysis. This has meant a heavy health burden for millions in the past. Global efforts combining surveillance, financial support to developing countries and immunization in the last 30 years have achieved a 99 % decrease in cases of poliomyelitis. However, since no real cure exists, a lot of effort has still to be made [1].

The antiquity of the condition is accepted, and commonly even traced back to Ancient Egypt. Two lines of evidence are adduced, pictorial and paleopathological. The ca. 1500 BCE stele of a priest called Ruma with a shorter leg and helping himself with a stick (Copenhagen, Ny Carlsberg Museum ÆIN 0134) is considered to be one of the first representations of a polio victim [2]. The famous relief in Berlin (Egyptian Museum Inventory 15000) showing a late Amarna royal couple (ca. thirteenth century BCE) is also

regarded to show the king as a polio victim with a shortened leg using a cane, yet it is even possible that the relief is a counterfeit or the clumsy work of a lesser artist [3].

Pharaoh Siptah's (1205–1187 BCE, Cairo, National Museum CG 61080) mummy shows a severely deformed *Pes equinovarus*-like left foot and a shortened left leg, a situation also encountered with the clubfoot of Khnumu-Nekht (ca. 2500 BCE, Manchester Museum, Inv. No. 21471): these may be interpreted either as evidence of neuromuscular disease suggestive of poliomyelitis infection [4] or (especially Siptah) as congenital malformations [2] or mummification-produced modifications.

In conclusion, while the paucity of potential cases identified may confirm that even in the past only a small percentage of cases manifested a full clinical syndrome, pictorial evidence alone gives no definitive proof, still lacking from mummies. Until further incontestable paleopathological data are produced, the presence of poliomyelitis in Ancient Egypt should be considered speculative.

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'HABICHT ME, EPPENBERGER PE, GALASSI FM, RÜHLI FJ, HENNEBERG M , 0: Queen Meresankh III – the oldest case of bilateral Silent Sinus Syndrome (c. 2620/10 - 2570 BC)? . *Anthropologie (Brno)* , : 0-0'.

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Abstract

The silent sinus syndrome is characterized by painless enophthalmia and hypotropia caused by chronic atelectasis of the maxillary sinus with onset in adulthood, typically between the third and the fifth decade of life. It is increasingly diagnosed as a result of today's widespread use of computed tomography (CT). The phenomenon was originally described in 1964 (Montgomery, 1964), while the term "silent sinus syndrome" was later introduced by Soparkar and colleagues in 1994. The pathogenic mechanism appears to involve chronic maxillary sinus obstruction with hypoventilation as well as the development of negative pressure within the sinus. While studying literature on crania of Egyptian royal families, photographs of the skull of Queen Meresankh III caught our attention because of the unusually shaped orbits, skull vault and suborbital areas. A retrospective craniometric analysis clearly suggests a pathological condition. Materials & Methods: In this multimodal, interdisciplinary study we reassessed the excavation report of Queen Meresankh III's mastaba tomb in Giza (Egypt) as well as a publication in the anatomical record (Dunham and Simpson, 1974). Precise craniometric measurements were obtained by application of a three-dimensional (3D) image reconstruction method, which was compared to reference data from two different databases. A differential diagnosis was established in consensus by the authors with regard to the found pathologic craniometric measurements as well as to the biographic information available from the historical sources. Results: Queen Meresankh III was an Ancient Egyptian queen of the 4th Dynasty (Old Kingdom, lifespan c. 2620/10-2570 BC). Her lifespan is reconstructed from the death date mentioned in her tomb. According to our measurements, her cranium shows unusual features and measurements outside the normal range. The maxillary sinuses are bilaterally reduced and the zygomatic arch is altered with a diminished lateral extent. The width of the skull is pathologically increased, while the cranial capacity is in a normal range. The orbit widths compare well with existing data, while orbit heights exceed ranges of normal women by more than 2 standard deviations. Conclusion: On account of the presented evidence, a retrospective diagnosis of Silent Sinus Syndrome for Queen Meresankh III may be reasonably postulated, making it the world's oldest case of the Silent Sinus Syndrome. Other considered differential diagnoses could either be ruled out based on craniometric measurements or biographic information. The impossibility to carry out further analyses on the queen's mortal remains at present, however, suggests caution in definitive interpretations. Should additional tests one day be possible to carry out, a more refined diagnostics could be achieved.

Keywords

Ancient Egypt, Old Kingdom, Mersyankh III, Meresankh III, Giza, skeleton, pathology, facial reconstruction

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A New Sothis Rise on a Small Cylindrical Jar from the Old Kingdom

(Collection of Prof. Peter A. Kaplony)

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2. Abstract

The ointment jar from the collection of late Professor Peter A. Kaplony can be stylistically dated to the Old Kingdom, most likely to the 5th or early 6th Dynasty. The inscription mentions the rise of Sothis on the IV. Akhet, day 1. Since the Egyptian civil calendar shifted towards reality one day in four years, the connection of a civil calendar date with the heliacal rising of Sothis is vitally important for the reconstruction of chronology. An assumed point of observation in Memphis dates this rise of Sirius to a time window 2419 to 2411 BC, depending on the arcus visionis.

https://www.uni-goettingen.de/de/jahrgang+2015+%28244-247%29/501409.html

Research Article

A New Astronomically Based Chronological Model for the Egyptian Old Kingdom

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A recently discovered inscription on an ancient Egyptian ointment jar mentions the heliacal rising of Sirius. In the time of the early Pharaohs, this specific astronomical event marked the beginning of the Egyptian New Year and originally the annual return of the Nile flood, making it of great ritual importance. Since the Egyptian civil calendar of 365 days permanently shifted one day in four years in comparison to the stars due to the lack of intercalation, the connection of a date from the Egyptian civil calendar with the heliacal rising of Sothis is vitally important for the reconstruction of chronology. The new Sothis date from the Old Kingdom (3rd–6th Dynasties) in combination with other astronomical data and radiocarbon dating re-calibrates the chronology of ancient Egypt and consequently the dating of the Pyramids. A chronological model for Dynasties 3 to 6 constructed on the basis of calculated astronomical data and contemporaneously documented year dates of Pharaohs is presented.

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