ANTHROPOLOGIE • LVI/2 • pp. 103–113 • 2018

MICHAEL E. HABICHT, PATRICK E. EPPENBERGER, FRANCESCO MARIA GALASSI, FRANK J. RÜHLI, MACIEJ HENNEBERG

QUEEN MERESANKH III – THE OLDEST CASE OF BILATERAL SILENT SINUS SYNDROME (C. 2620/10–2570 BC)?

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.

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.

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 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.

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

Received 19 May 2017; accepted 25 September 2017.

DOI: http://dx.doi.org/10.26720/anthro.17.09.25.2

diagnoses could be either 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.

KEY WORDS: Ancient Egypt – Old Kingdom – Mersyankh III – Meresankh III – Giza – Skeleton – Pathology – Facial reconstruction

INTRODUCTION

The silent sinus syndrome (SSS) 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 (Cobb *et al*. 2012, Illner *et al*. 2002). The phenomenon was originally described in 1964 (Montgomery 1964), while the term "silent sinus syndrome" was later introduced by Soparkar and colleagues in 1994 (Soparkar *et al*. 1994). Numerous cases have been reported ever since in the otolaryngological and ophthalmological literature (Bahgat *et al*. 2012, Boyd *et al*. 1998, Canzi *et al.* 2015, Davidson *et al*. 1999, Gan 2014, Gillman *et al*. 1999, Hunt, Tami 2000, Illner *et al.* 2002, Kass *et al*. 1997, 1996, Montgomery 1964, Soparkar *et al*. 1994, Wan *et al*. 2000), as it is increasingly diagnosed as a result of today's widespread use of computed tomography (CT), which allows a better defined and higher quality visualisation of the oro-facial region and structures (Illner *et al*. 2002, Rege *et al*. 2012).

Most published cases report unilateral occurrence, often causing diplopia and blurred vision, bilateral cases, though less frequent, have been described as well (Canzi *et al.* 2015, Gan 2014, Numa *et al*. 2005). Patients typically complain about nasal obstruction, chronic maxillary sinusitis and aesthetically unpleasant changes in appearance, such as eyelid retraction, deepening of the superior orbital sulcus as well as a flattening of the malar region. In clinical practice differential diagnoses include blow-out-fracture of the orbital floor, soft tissue atrophy, primary or secondary malignant neoplasm, malformation of the veins of the orbit, interrupted bone growth after radiation therapy, congenital causes (slight hemifacial microsomy, plagiocephaly, microphthalmia, etc.) and pseudo-enophthalmus (unilateral blepharoptosis, Horner's syndrome, contralateral exophthalmia, contralateral high-grade myopia, contralateral retraction of the lid). Surgery is the only available treatment option (Gan 2014, Illner *et al*. 2002, Rege *et al*. 2012). The pathogenic mechanism appears to involve chronic maxillary sinus obstruction with hypoventilation as well as the development of negative pressure within the sinus. This negative pressure is possibly caused either by masticatory movements or blood circulation within the sinus (McCulley *et al*. 2015). A low-grade inflammatory response, likely caused by the accumulation of mucus, then leads to osteolytic thinning of the sinus walls, which are eventually pulled into the sinus by the negative pressure. Sinus reduction remains aseptic and mostly asymptomatic, until the translocation of the eyeball produces the mentioned symptom complex [diplopia (double vision), pseudo-retraction of the upper eye lid, hypoglobus, enophthalmos (sinking of the eyeball) etc.] (McCulley *et al.* 2015, Van der Meer *et al.* 2001).

There is no reason to assume that such blockages of communication between the sinuses and the nasal cavity could not have occurred in the past. Since its development is mostly asymptomatic, it is plausible that descriptions of silent sinus syndrome may not be found in the historical record. Since morphological features of human skulls are naturally variable, including variation in the size of maxillary sinuses and the orbits, some of the reduced sinus sizes may, until now, not have come to the attention of palaeopathologists.

While studying crania of Egyptian royal families, a female skull caught our attention because of its unusually shaped orbits, skull vault and suborbital areas. A retrospective craniometrical analysis clearly suggests a pathological condition.

MATERIALS AND 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, Simpson 1974). We obtained precise craniometric measurements by applying a three-dimensional (3D) image reconstruction method, which was compared to reference data from two different databases. The first is the well-established Howell's Database: (Howells 1973),

the second is a newly created and still unpublished craniometric database of the Institute of Evolutionary Medicine of the University of Zurich, using data from Ancient Egypt (Old Kingdom, 3rd to 6th dynasty females, n = 164) which are based on published studies (Derry 1912, Thomson, MacIver 1905). 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. Additionally, we performed a facial approximation to better illustrate and corroborate our conclusions.

HISTORICAL BACKGROUND

Queen Meresankh III (also transliterated Mersyankh, Egyptian *mr = s-ankh*) 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 in her tomb (1st year, *Shemu*-season, 21st day, probably under King Menkaure) and a new astronomical dating model, dating this year c. 2570 BC (Gautschy *et al.* 2017). She was the daughter of Crown-prince Kawab (possibly a son of King Khufu or King Seneferu) and Queen Hetepheres II, a daughter of King Khufu (Dodson, Hilton 2004). Meresankh III was married to her uncle, King Khaefra, another son of Khufu. From this marriage, eight children are known who reached adult age: Duaenre and Nebemakhet, both incumbents of the office of vizier (prime minister), Prince Niuserre, Prince Khenterka, Prince Ankhemre, Princess Shepsetkau and two other daughters (names unknown). Meresankh III carried impressive titles such as: *mAAt Hr St* (she who sees Horus and Seth); *sAt nsw* (king's daughter), *wrt Hts* (Great of Sceptre), *Hm.t nsw* (king's wife) among others. According to her mortal remains she reached an age over 50 years. Anatomical age estimation and historical reconstruction of her lifespan conclude that she was born during the reign of Khufu and lived through the reigns of Radjedef and Khafra and died either in the first year of Menkaure when she was in her mid-40ies or approximately 19 years later in the first year of Shepseskaf (in her mid-60ies). She was buried in a large double mastaba tomb (Giza G 7530–5440). The tomb was originally intended for her mother – who survived her – and it is assumed that Meresankh III probably died unexpectedly, as the tomb was originally intended for her mother Hetepheres II and redecorated for Meresankh III (Reisner 1927).

However, this interpretation is speculative since no further information upon the matter exists. Artistic representations depicted Meresankh III as a lady with normal stature, slightly shorter than her mother, at times wearing either a tight black cap-crown or short cut black hair (Reisner 1927), in other reliefs longer hair; she has large eyes and a prominently broad head in three dimensional art, such as in the Statue of Hetepheres II and Meresankh III in Boston (Boston MfA, Inv. No. 30.1456). If one trusts the depictions in the mastaba, she had a close relation with her mother.

The colour of her eyes and skin is uncertain, thus the yellowish-ochre of the classic Egyptian art canon (Old Kingdom) was chosen for her depictions. It has to be remarked that Meresankh III appears with that colour, while her mother Hetepheres I, standing in front of her in the reference relief, is depicted with rather fair skin and sometimes with short blonde hair. It remains unclear whether her natural hair colour was naturally blonde (Staehlin 1966: 174, 179), dyed with henna (*Lawsonia inermis)*, or she used to wear a blonde wig (Dunham, Simpson 1974: 5, Smith 1960: 51). Royal mummies from the New Kingdom are reported to show traces of dyeing of the hair with henna (Smith 1912). The golden yellow colour of her hair might have also emphasised her solar attributions (Fletcher 2015: 79). Regarding her ancestry, minimal information is available: George A. Reisner (1867–1942) and Hermann Juncker (1877–1962) suspected a foreign extraction for Hetepheres II (Dunham, Simpson 1974: 2), yet, as Hetepheres II's body is missing, such claims can neither be confirmed nor dismissed.

The remains of Meresankh III are among those considered to be authentic royal remains from the Old Kingdom (Habicht *et al*. 2016a, b, Strouhal *et al*. 2001, 1993, Strouhal, Vyhnánek 2000).

Furthermore, Meresankh III was a priestess of Thoth, God of literature (Dunham, Simpson 1974: 8, Fletcher 2015: 79). Biographical information suggesting the performance of royal and religious functions depicted in her tomb decoration might well exclude potential diagnoses since, in addition, no evidence of impaired mental capacities are recorded.

ANTHROPOLOGICAL DESCRIPTION BY DOUGLAS DERRY

Douglas E. Derry (1874–1961) removed Meresankh III's remains from the sarcophagus on 16. December 1927. Derry restored the skull, which lay broken in

several pieces, with the whole face "broken away" (*Figures 1–4*). A full restoration was accomplished with the exception of "a portion of the base [*viz*. of the skull], involving the *foramen magnum*" (Dunham, Simpson 1974: 21–22). Derry further noted:

- "When repaired, the skull was seen to be very broad and flat-topped, a type of head very commonly represented in the statues and pictures of the period. Indeed, the mother of the Queen, Hetepheres II, whose portrait in color is painted on the wall of this tomb, is shown with flat-topped head..."
- "The skull of Mersyankh III is remarkable in giving a width measurement of no less than 147.0m/m, only less than that of Akhenaten. The writer can only recall meeting an equal width of skull in a woman...Mena's wife having a skull width of 143.0 m/m [*sic*: m/m for mm], and the second of Dynasty 12, giving 144.5 m/m..."
- "Although all of these are unusually large, yet the examples serve to lay stress on one of the racial characteristics of the people of the Old Kingdom..."
- "Mersyankh was probably over fifty years of age at the time of her death. The cranial sutures with the exception of the frontal are either entirely closed or closing. The bone in the occipital region is reduced to almost paper thinness and the sinuses reveal extensive absorption. The teeth are much worn, and on the right side of the upper jaw the molars had been lost before death, leaving a large area of absorbed bone suggesting that there had been abscesses at the roots. On the left side the first molar tooth had also disappeared before death. The remaining teeth, though worn, were sound. The face is narrow and slopes gradually from the forehead, a feature which is very characteristic of this race..."
- "The nose is narrow with a moderately high bridge, but not aquiline."
- "All of the vertebrae were present with the exception of the 5th, 6th and 7th cervical. In view of the damage done to the body by tomb robbers and the fact that a piece of gold was found attached to the 1st cervical vertebra, the absence of the three vertebrae mentioned is probably significant. The same remark may apply to the hands, both of which with the exception of the 2nd left metacarpal bone, had entirely disappeared. Some of the bones of both feet still remained. The pelvis is large and roomy. As pointed out elsewhere by the writer, the pelves of the Old Kingdom Egyptian women are most remarkable in this regard and form a striking contrast when compared with those of Predynastic woman."

Derry used the Pearson (Pearson 1899) formulae to calculate her body height, obtaining a result of approximately five feet and ½ inch (c. 1,540 mm).

FIGURE 1: Skull of Meresankh III, frontal view. Photograph © [1927] Museum of Fine Arts, Boston. With kind permission by the Museum of Fine Arts Boston.

FIGURE 2: Skull of Meresankh III, back view. Photograph © [1927] Museum of Fine Arts, Boston. With kind permission by the Museum of Fine Arts Boston.

DIGITAL SKULL RECONSTRUCTION

Based on three of the available four photographs (Dunham, Simpson 1974) in frontal, axial and lateral view (*Figures 1–4*) a 3D line model using dedicated 3D modelling software (Rhinoceros, Version 5.2.4. Robert McNeel & Associates, Seattle, USA) was reconstructed, from which then the craniometric measurements were derived (*Figures 5–7*). Digital high resolution scans (of the original four photographs (frontal, axial, lateral and rear view), used by Dunham & Simpson for their 1974 publication, could be obtained from the Boston Museum of Fine Art in the tagged image file format (TIFF). Further information on the camera equipment or type of lens used at the time is not listed in the publication. The approach to reconstruct a 3D line model was chosen, since these four available photographs would not permit a standard photogrammetric reconstruction, as frequently used in archaeological research (Barreau *et al.* 2015, Grün *et al*. 2004, Mathys *et al*. 2013, Remondino, Campana 2014, Viti 2010). The images in frontal, axial and lateral view were chosen, since they contain the most identifiable landmarks, as opposed to the rear view image, which was essential for the following processing steps. Rhinoceros was chosen as 3D modelling software to construct the 3D line-model, since it is a very versatile instrument for working with curves, surfaces, point clouds, and polygon meshes in 3D space, which we have previously used for post processing of diagnostic imaging and surface scan data. The applied reconstruction method was developed by co-author Patrick Eppenberger, with over 15 years of experience in 3D modelling with Rhinoceros. To account for the photographs inherent perspective distortion, which is determined by the relative distance at which an object is photographed, an iterative estimation of the original position of the camera's focal-point, relative to the skull, was applied, starting with an estimated distance of 1,000 mm. Several iterative processing steps were then manually performed. The three chosen photographs (frontal, axial and lateral view) were alternately repositioned and scaled to approximate the original three camera positions relative to each other in 3D space. Landmarks, which were clearly identifiable on at least two of the three images at the same time, were used as references. Once the three camera positions were approximated, two-dimensional (2D) line drawings were derived from each photograph, before a 3D line model was reconstructed by back-projection of the 2D line models to the approximated focal-point positions in all three dimensions. In a final step the proper scale of the reconstructed 3D line model could be established trough the centimetre-scale included on all three images as well as the known cranial breath of 147 mm (Dunham, Simpson 1974).

FIGURE 3: Skull of Meresankh III, upper view. Photograph © [1927] Museum of Fine Arts, Boston. With kind permission by the Museum of Fine Arts Boston.

FIGURE 4: Skull of Meresankh III, lateral view. Photograph © [1927] Museum of Fine Arts, Boston. With kind permission by the Museum of Fine Arts Boston.

TABLE 1: Anthropometric measurements (mm) of Queen Meresankh III.

	Derry	Reconstructed measurements	Howells (SD)	IEM database (SD)	Z-score Howells	Z-score IEM
Body height	1,540	1,540	no data	1,530	no data	no data
Cranial breadth	1,470	1,470	135.6 (4.4)	130.9 (5.8)	2.60	2.80
Cranial length		181.7	175.6 (4.5)	174.9 (5.52)	1.35	1.23
Basiobregm. height		130	127.4 (4.0)	129.67 (4.86)	0.65	0.07
Auricular height		107	no data	no data	no data	no data
Cranial Index		80.5	77.2 (2.8)	74.94 (3.7)	1.18	1.5
Cranial capacity (cm^3)		1,091	no data	1,260 (101.21)	no data	-1.67
Min. frontal breadth		101	91.7 (2.9)	87.67 (2.84)	3.2	4.70
Nose length		54	49.0 (2.3)	48.63 (3.16)	2.17	1.70
Nose width		25	24.0 (1.6)	24.8 (1.87)	0.60	0.10
Upper facial height		74	64.1 (3.3)	66.35 (3.95)	3.0	1.90
Right orbit height		37.9	32.8 (1.82)	no data	2.9	no data
Right orbit breadth		39.1	37.9 (1.61)	no data	0.7	no data
Left orbit height		38.6	no data	no data	3.10	no data
Left orbit breadth		39.5	no data	no data	1.00	no data
Orbit index right		96.93	86.7 (4.4)	no data	2.30	no data
Orbit index left		97.72	no data	no data	2.50	no data

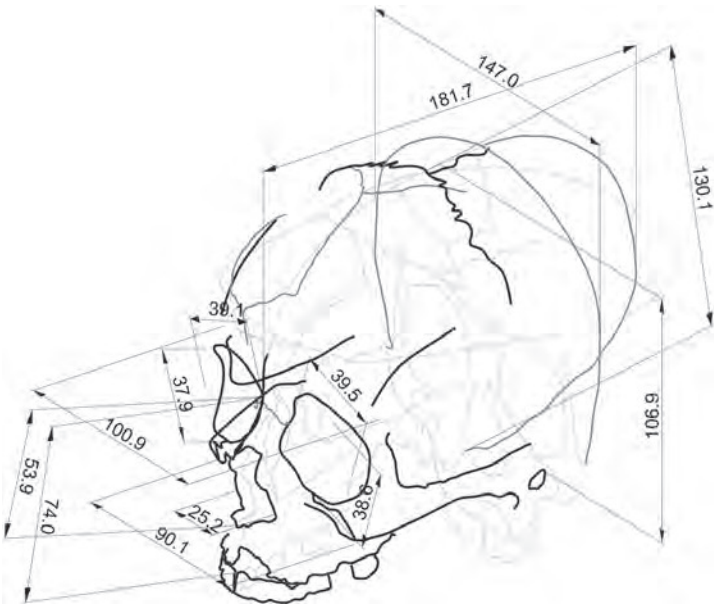

FIGURE 5: 3D reconstruction of Meresankh III's skull.

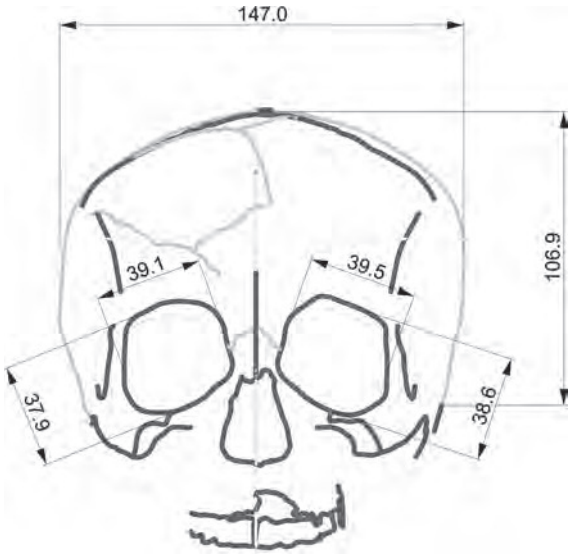

FIGURE 6: Frontal reconstrution of Meresankh III's skull.

The facial soft tissue was reconstructed using data from a meta-analysis (Stephan, Simpson 2008), the shape of the nose, using the method of Prokopec and Ubelaker (Stephan *et al*. 2003). The profile view shows a protrusion of the mandible, based on an estimation of the mandibular-dimensions in accordance to the overall proportions of the cranium. The tight black cap and the wide *usekh*-collar made of faience pearls are derived from the wall depictions of her tomb (Main room, west wall, north end) and jewellery style of the Old Kingdom (Aldred, Shoucair 1971, Dunham, Simpson 1974, Müller, Thiem 1998).

RESULTS

The remains of Queen Meresankh III do not show any sign of very old age, no osteophytes or other degenerative alterations are distinguishable on the available images of her skeletal remains. The long bones indicate normal body proportions. Her body height, calculated by Derry, is within the normal range of her time period (mean 1,570–1,600 mm) (Habicht *et al*. 2015, Zakrzewski 2003). According to our measurements, the skull shows, however, unusual features and measurements beyond the normal range as listed in *Table 1*. The maxillary sinuses are bilaterally reduced and the zygomatic arch is altered with a diminished lateral extent (bizygmatic breadth 90.1 mm). The width of the skull is pathologically increased, while the cranial capacity (1,091 ml^3) is in a normal range. The orbit widths compare well with Howells's Egyptians and IEM data, while orbit heights exceed ranges of normal women by more than 2 standard deviations (*Table 1*). Reconstructed from historical records and age assessment of her remains, Queen Meresankh III reached an above-the-average to an even advanced age for her time period. Furthermore, we know that she gave birth to at least eight children who reached adulthood. Her mother, Queen Hetepheres II lived even longer and died after her. Derry remarked the resemblance of her skull to contemporary art of the Old Kingdom (Dunham, Simpson 1974: 21–22). In view of the highly formalised art canon used in Ancient Egypt, however, such comparisons should be made with caution. In case of Meresankh III at least some resemblance between artistic representation and her actual appearance can be assumed, as we also reconstructed facial soft tissue using data from a meta-analysis (Stephan, Simpson 2008), the shape of the nose, using the method of Prokopec and Ubelaker (Prokopec, Ubelaker 2002, Stephan *et al*. 2003; *Figures 8–9*).

TABLE 2: Orbital index (Howells) for female Egyptians (N = 52) in mm.

Orbit height	Mean: 32.83	SD: 1.82
Orbit breadth	Mean: 37.97	SD: 1.61
Orbit index (ht/w)	Mean: 86.70	SD: 4.40

DISCUSSION

We suggest that Queen Meresankh III suffered from bilateral Silent-Sinus-Syndrome as the most plausible explanation for her pathological cranial features after considering all the available sources (data from craniometric reconstruction and historical and biographical information). In clinical practice, a suspected diagnosis of silent sinus syndrome is radiologically confirmed by a CT-scan, showing maxillary sinus outlet obstruction, sinus opacification, and sinus volume loss caused by inward retraction of the sinus walls. A meta-analysis by Numa counted 84 reported cases (Numa *et al.* 2005). The mean age of modern patients in that study was 39 years and the syndrome was slightly more common in male than female patients were 28% of them suffered from diplopia and all had signs of enophthalmos – which however cannot be verified in Meresankh's case. In our paleopathological approach, we primarily have to rely on the craniometrical

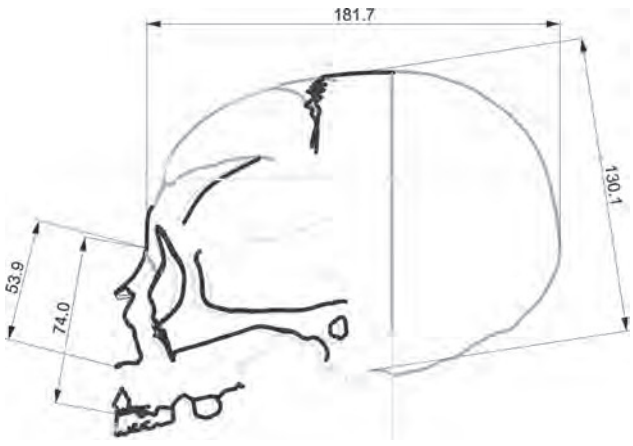

FIGURE 7: Lateral reconstrution of Meresankh III's skull.

measurements. This also implies a wider range of possible differential diagnoses, such as Down syndrome, thalassemia or elevated intracranial pressure (ICP).

Her advanced age and the fact that she gave birth to at least eight children who reached adulthood likely exclude any disease or syndrome affecting fertility or drastically reducing her life expectancy (Dodson, Hilton 2004), also including Thalassemia major (or intermedia). Down syndrome, in which sinuses are reduced together with enlarged and hyperteloric orbits can be excluded (the advanced age, high fertility and prognathism are incompatible with Down syndrome). The cranial capacity of Meresankh III being normal, her advanced age at death, her outstanding fertility and apparently unaffected mental abilities, as shown by the performance of royal functions depicted in her tomb decoration, clearly argue against the diagnosis of the Down syndrome. In addition, fertility in Down syndrome patients is low and even in 1912 AD the average life expectancy of people with Down Syndrome was only about 12 years of age (Malt *et al*. 2013, Roizen *et al.* 2010: 108). Furthermore, while Down's syndrome in the Old World has been shown to be ancient (Czarnetzki *et al*. 2003), as far as Ancient Egypt is concerned, the sole suggestion as to its presence comes from a 100AD (Roman period) terracotta figurine (Starbuck 2011). We also exclude any conditions involving increased intracranial pressure (McCulley *et al.* 2015) as the cranium would most likely have enlarged in all dimensions (McCulley *et al.* 2015), while the skull of Meresankh III only expanded in width while the length and height remained in a normal range. Our measurements in fact show that the frontal width and total breadth of the braincase, both exceed more than 2 standard deviations above the mean.

In bilateral silent sinus syndrome sinuses grow smaller and the orbit floors eventually descend so that the orbits become larger and their inlets approach an abnormal 1:1 height to width proportion. This applies for the Meresankh' skull where orbit widths compare well with Howells's database Egyptians and afore mentioned IEM database, while orbit heights exceed ranges of normal women by more than 2 standard

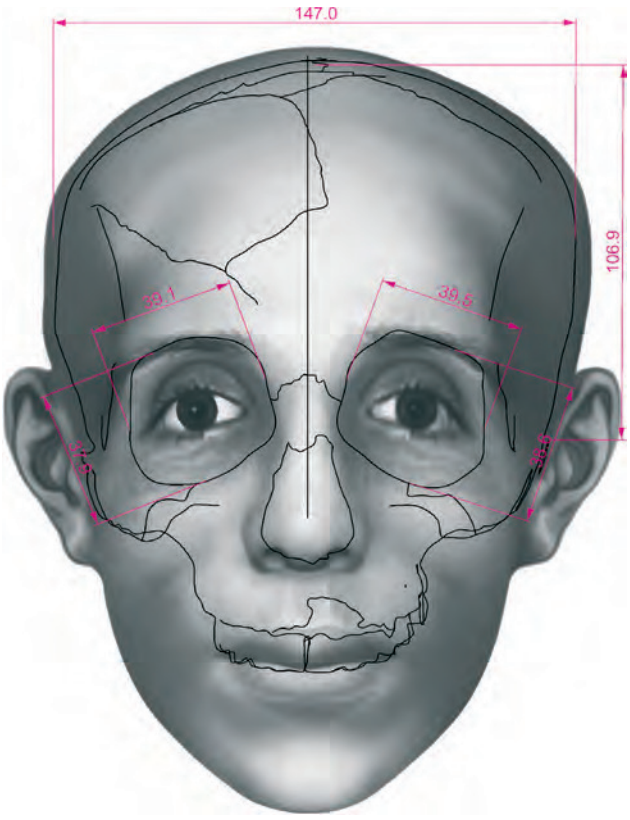

FIGURE 8: Facial approximation with overlaid skull.

FIGURE 9: Facial approximation of Queen Meresankh III (gracefully aged 50).

deviations. Consequently the orbital index (100*Ht/width) values exceed 100 when compared with approximately 85 % of normal Egyptian women. Therefore, this difference is highly suggestive of a pathological condition. Since the collapse of maxillary sinuses also changes the biomechanical properties of the maxillae and adjacent bones, likely the morphology of the entire skull is affected. Thus, we propose a biomechanical remodelling, induced by an altered transmission of forces in the masticatory process, which, after the collapse of the maxillary sinuses, are more directed towards the forehead, rather than being partly distributed through the zygomatic bones and zygomatic arches. The forehead expanded more than the cranium, as the chewing forces are greater in the forehead. As a result, the suggested silent sinus syndrome must have developed much before her death for such a remodelling of the skull to develop.

The limitations of this paleopathological study lie in the fact that we did not have direct access to the skeletal remains of Meresankh' III and we therefore had to rely on published sources with only a few confirmed measurements by Derry (Dunham, Simpson 1974).

CONCLUSION

On account of the evidence presented here, a retrospective diagnosis of silent sinus syndrome for Queen Meresankh III may be reasonably postulated. If that truly were the case, Meresankh III's would be the world's oldest case of this disease to this date – to the best of our knowledge. The rather abnormal facial appearance of the skull of a member of the royal family, so far largely misunderstood, neglected or even the subject of the most exuberant of interpretations, can now be explained by a somewhat rare but existing medical condition. The impossibility to carry out further analyses on the queen's mortal remains at present, however, suggests caution in definitive interpretations. Should it be possible one day to carry out additional tests, a more refined diagnosis could be achieved.

AKNOWLEDGMENTS

We wish to express our gratitude to Ms. Carolyn Cruthirds, responsible for coordination of image licensing from the Museum of Fine Arts, Boston for providing us with hi-resolution scans of the original pictures. This article was sponsored by funding of the Swiss National Science Foundation (*The Canopic Jar Project* – grant number: 162803), Mäxi Foundation, Zurich, Switzerland, Cogito Foundation, Zurich, Switzerland and the Athenaeum Stiftung – Dietrich Götze Stiftung für Kultur und Wissenschaft, Heidelberg, Germany.

REFERENCES

ALDRED C., SHOUCAIR A., 1971: The Jewels of the Pharaohs: Egyptian jewellery of the Dynastic Period. London: Thames and Hudson, London.

BAHGAT M., BAHGAT Y., BAHGAT A., 2012: Silent sinus syndrome. BMJ Case Rep. bcr2012007198. doi:10.1136/bcr-2012-007198

BARREAU J.-B., NICOLAS T., BRUNIAUX G., PETIT E., PETIT Q., BERNARD Y., GAUGNE R., GOURANTON V., 2015: Photogrammetry Based Study of Ceramics Fragments. *Int. J. Herit. Digit. Era* 3: 643–646.

BOYD J. H., YAFFEE K., HOLDS J., 1998: Maxillary sinus atelectasis with enophthalmos. *Ann Otol Rhinol Laryngol* 107: 34–39.

CANZI G., MORGANTI V., NOVELLI G., BOZZETTI A., SOZZI D., 2015: Posttraumatic Delayed Enophthalmos: Analogies with Silent Sinus Syndrome? Case Report and Literature Review. Craniomaxillofac. *Trauma Reconstr*. 8: 251–256. doi:10.1055/s-0034-1399799

COBB A.R., MURTHY R., COUSIN G.C., EL-RASHEED A., TOMA A., UDIN J., MANISALI M., 2012: Silent sinus syndrome. *Silent sinus Syndr.* 50: e81–5.

CZARNETZKI A., BLIN N., PUSCH C. M., 2003: Down's syndrome in ancient Europe. *Lancet* 362: 1000.

DAVIDSON J. K., SOPARKAR C. N., WILLIAMS J. B., PATRINELY J. R., 1999: Negative sinus pressure and normal predisease imaging in the silent sinus syndrome. *Arch Ophthalmol* 117: 1653–1654.

DERRY D. E., 1912: *Report on the human remains found by Junker in a cemetery at Turah, Egypt.* Denkschriften der Akad. der Wissenschaften Wien. Phil.-hist. Cl. 56.

DODSON A., HILTON D., 2004: The Complete Royal Families of Ancient Egypt. Thames & Hudson.

DUNHAM D., SIMPSON W. K., 1974: *The Mastaba of Queen Mersyankh III. G 7530–7540*. BMFA, Boston.

FLETCHER J., 2015: *The Story of Egypt.* Hodder and Stroughton, London.

GAN W.L., 2014: Silent sinus syndrome as a recognized cause of unilateral painless enophthalmos. *BMJ Case Rep*. bcr2014203954. doi:10.1136/bcr-2014-203954

GAUTSCHY R., HABICHT M. E., GALASSI F. M., RUTICA D., HANNIG R., RÜHLI F. J., 2017: A new astronomically based chronological model for the Egyptian Old Kingdom. *J. Egypt. Hist.* 10, 2: 69–108. doi: 10.1163/18741665-12340035

GILLMAN G. S., SCHAITKIN B. M., MAY M., 1999: Asymptomatic enophthalmos: the silent sinus syndrome. *Am J Rhinol* 13: 459–462.

GRÜN A., REMONDINO F., ZHANG L., 2004: Photogrammetric Reconstruction of the Great Buddha of Bamiyan, Afghanistan. *Photogramm. Rec.* 19: 177–199.

HABICHT M. E., BIANUCCI R., BUCKLEY S. A., FLETCHER J., BOUWMAN A. S., ÖHRSTRÖM L. M., SEILER R., GALASSI F. M., HAJDAS I., VASSILIKA E., BÖNI T., HENNEBERG M., RÜHLI F. J., 2016a: Queen Nefertari, the Royal Spouse of Pharaoh Ramses II: A Multidisciplinary Investigation of the Mummified Remains Found in Her Tomb (QV66). *PLoS One* 11: e0166571. doi:10.1371/journal.pone.0166571

HABICHT M. E., BOUWMAN A. S., RÜHLI F. J., 2016b: Identifications of ancient Egyptian royal mummies from the 18th Dynasty reconsidered. *Am. J. Phys. Anthropol.* 159: S216-31. doi:10.1002/ajpa.22909

HABICHT M. E., HENNEBERG M., ÖHRSTRÖM L. M., STAUB K., RÜHLI F. J., 2015: Body Height of Mummified Pharaohs Supports Historical Suggestions of Sibling Marriages. *Am. J. Phys. Anthropol*. 157: 519–525. doi:10.1002/ajpa.22728

HOWELLS W. W., 1973: *Cranial Variations in Man. A Study by Multivariante Analysis of Patters of Differences Among Recent Human Populations*. Pap. Peabody Museum Archaeol. Ethnol. 67.

HUNT S. M., TAMI T. A., 2000: Sinusitis-induced enophthalmos: the silent sinus syndrome. *Ear Nose Throat J* 79, 576: 579–581, 584.

ILLNER A., DAVIDSON H. C., HARNSBERGER H. R., HOFFMAN J., 2002: The Silent Sinus Syndrome. *Am. J. Roentgenol.* 178: 503–506.

KASS E. S., SALMAN S., MONTGOMERY W. W., 1996: Manometric study of complete ostial occlusion in chronic maxillary atelectasis. *Laryngoscope* 106: 1255–1258.

KASS E. S., SALMAN S., RUBIN P. A. D., WEBER A. L., MONTGOMERY W. W., 1997: Chronic maxillary atelectasis. *Ann. Otol Rhinol Laryngol* 106: 109–116.

MALT E. A., DAHL R. C., ULVESTAD T. M., EMILSEN N. M., B. HANSEN Y. E. C., SKØLD O. R., THORSEN A.T., DAVISEN E. M., 2013: Health and disease in adults with Down syndrome. *Tidsskr. Nor. Laegeforen.* 133: 290–294. doi:10.4045/tidsskr.12.0390

MATHYS A., BRECKO J., SEMAL P., 2013: Comparing 3D digitizing technologies: what are the differences? In: A.C. Addison, L. De Luca, G. Guidi, S. Pescarin, S. (Eds.): *Proceedings of the Digital Heritage International Congress*. Vol. 1. Marseille: CNRS, 2013. Marseille.

MCCULLEY T. J., PILUEK W. J., CHANG J., 2015: Intracranial pressure and skull remodeling. *Saudi J. Ophthalmol*. 29: 57–62. doi:10.1016/j.sjopt.2014.12.003

MONTGOMERY W. W., 1964: Mucocele of the maxillary sinus causing enophthalmos. *Eye Ear Nose Throat Mon*. 43: 41–44.

MÜLLER H. W., THIEM E., 1998: *Die Schätze der Pharaonen*. Battenberg, Augsburg.

NUMA W. A., DESAI U., GOLD R. R., HEHER K. L., ANNINO D. J., 2005: Silent Sinus Syndrome: A Case Presentation and Comprehensive Review of All 84 Reported Cases. *Ann. Otol. Rhinol. Laryngol.* 114: 668–694.

PEARSON K., 1899: 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* 192: 169–244. doi:10.1098/rsta.1899.0004

PROKOPEC M., UBELAKER D., 2002: *Reconstructing the shape of the nose according to the skull.* Forensic Sci. Commun. 4, 1: 1–4.

REGE I. C. C., T. O. SOUS, C. R. L., MENDONÇA E. F., 2012: Occurrence of maxillary sinus abnormalities detected by cone beam CT in asymptomatic patients. *BMC Oral Health* 12: 30. doi:10.1186/1472-6831-12-30

REISNER G. A., 1927: The Tomb of Meresankh, a Great-Granddaughter of Queen Hetep-Heres and Sneferuw. *Bull. Museum Fine Arts* 25: 64–79.

REMONDINO F., CAMPANA S., 2014: *Recording and Modelling in Archaeology and Cultural Heritage*. Theory and best practices (BAR International Series 2598). BAR International Series, Oxford.

ROIZEN N. J., URBANO R. C., HODAPP R. M., MIODRAGI N., GOLDMAN S. E., 2010: Overview of health issues in Down Syndrome. In: *International Review of Research in Mental Retardation.* Academic Press.

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

SMITH W.S., 1960: *A History of Egyptian Sculpture and Painting in the Old Kingdom*. 5th ed. Museum of Fine Arts Boston, Osford.

SOPARKAR C. N., PATRINELY J. R., CUAYCONG M. J., 1994: The silent sinus syndrome. A cause of spontaneous enophthalmos. *Ophthalomolgy* 101: 772–778.

STAEHLIN E., 1966: Untersuchungen zur ägyptischen Tracht im Alten Reich. MÄS 8.

STARBUCK J. M., 2011: On the Antiquity of Trisomy 21: Moving Towards a Quantitative Diagnosis of Down Syndrome in Historic Material Culture. *J. Contemp. Anthropol.* 2: 18–29.

STEPHAN C. N., HENNEBERG M., SAMPSON W., 2003: Predicting Nose Projection and Pronasale Position in Facial Approximation: A Test of Published Methods and Proposal of New Guidelines. *Am. J. Phys. Anthropol.* 122: 240–250.

STEPHAN C. N., SIMPSON E. K., 2008: Facial Soft Tissue Depths in Craniofacial Identification (Part I): An Analytical Review of the Published Adult Data. *J Forensic Sci* 53: 1257–1272. doi:10.1111/j.1556-4029.2008.00852.x

STROUHAL E., GABALLA M. F., KLIR P., NĚMEČKOVÁ A., SAUNDERS S. R., WOELFLI W., 1993: King Djedkare Isesi and his daughters. In: W. V. Davies, R. Walker (Eds.): *Biological Anthropology and Study of Ancient Egypt*. Pp. 104–118. British Museum Press, London.

STROUHAL E., VYHNÁNEK L., 2000: The identification of the remains of King Neferefra. In: M. Bárta (Ed.): *Abusir and Saqqara in the Year 2000*. Pp. 551–560. Prag.

STROUHAL E., VYHNÁNEK L., GABALLAH M. F., SAUNDERS S. R., WÖLFLI W., BONANI G., NĚMEČKOVÁ A., 2001: Identification of Royal Skeletal Remaims from Egyptian Pyramids. *Anthropologie (Brno)* 39, 1: 15–23.

THOMSON A., MACIVER D. R., 1905: *The ancient races of the Thebaid. being an anthroopmetrical study of the inhabitants of Upper Egypt from the earliest prehistoric times to the Mohammedan conquest based upon the examination of over 1500 crania*. Clarendon Press, Oxford.

VAN DER MEER J. B., HARRIS G., TOOHILL R. J., SMITH T. L., 2001: The silent sinus syndrome: a case series and literature review. *Laryngoscope* 111: 975–978.

VITI S., 2010: Computer Graphics and Virtual Reality: two Different Contributions in Archaeological Research. In: F. Nicolucci, S. Hermon (Eds.): *Virtual Representations of the Past.* Proceedings of CAA2004, Prato 13–17 April 2004. Pp. 341–346. Archaeolingua, Budapest. Archaeolingua, Budapest.

WAN M. K., FRANCIS I. C., CARTER P. R., GRIFFITS R., VAN ROOIJEN M. L., CORONEO M. T., 2000: The Spectrum of Presentation of Silen Sinus Syndrome. *J. Neuroophthalmol.* 20: 207–212.

ZAKRZEWSKI S. R., 2003: Variation in ancient Egyptian stature and body proportions. *Am. J. Phys. Anthropol.* 121: 219–229.

Michael E. Habicht[*Δ]
Patrick E. Eppenberger[Δ]
Francesco Maria Galassi[Δ]
Frank J. Rühli
Maciej Henneberg
Institute of Evolutionary Medicine
University of Zurich
Winterthurerstrasse 190
8057 Zürich
Switzerland
E-mail: michael.habicht@iem.uzh.ch
E-mail: patrick.eppenberger@iem.uzh.ch
E-mail: francesco.galassi@iem.uzh.ch
E-mail: frank.ruehli@iem.uzh.ch

Michael E. Habicht
College of Humanities, Art and Social Science (Department of Archaeology)
Flinders University, Adelaide (Australia)
Flinders University
Adelaide, SA 5005
Australia
E-mail: michael.habicht@flinders.edu.au

Maciej Henneberg
University of Adelaide
Adelaide Medical School
Adelaide, SA 5005
Australia
E-mail:
maciej.henneberg@adelaide.edu.au

[*] Corresponding author; [Δ] equal contribution