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Computed tomography of the heads of ancient Egyptian mummies: a systematic review of the medical literature.

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Abstract

Objective: To summarize the current knowledge on CT scanning of Egyptian mummy heads and faces and provide more valid methodology than that previously available.

Material and methods: A systematic review was performed by one observer using two biomedical databases: PubMed and EMBASE. Inclusion and exclusion criteria were applied along with language restrictions. Finally, 2120 articles were found, 359 articles were duplicated among all search equations, 1454 articles were excluded, 307 articles were retained for full review, and 28 articles (31 mummies) were selected for the final study (PRISMA workflow).

Results: The data were categorized into the following groups: 1) general information; 2) 1st author affiliation; 3) CT radiological protocol; 4) excerebration pathways; 5) soft tissue preservation; 6) dental status and displaced teeth; 7) packing of the mouth, ears, nose, and eyes, and 8) outer facial appearance. The evidence-based quality of the studies was low because only case reports and small case series were found.

Discussion: The embalming art applied to a mummified head and face shows great variability across the whole span of Egyptian civilization. The differences among the various embalming techniques rely on multiple tiny details that are revealed by meticulous analysis of CT scans by a multidisciplinary team of experts.

Conclusion: There is a need for more systematization of the CT radiological protocol and the description of Egyptian mumm'y heads and faces to better understand the details of embalming methods.

Keywords: Egyptian mummy, embalming, computer tomography, systematic review, head, face

Introduction

Studies on ancient Egyptian embalming procedures started in the XVIth century [1]. However, the first attempt to provide an evidence-based approach to categorize and systematize this field of research was first performed by Zweifel et al., in 2009 [2]. Zweifel's systematic review was mainly focused on all types of articles related to egyptian mummification [2]. The selection of articles was based on only one database (PubMed). The strength of systematic review methodology relies on its repeatability over time, which is also one of the main components in scientific methodology. To conduct a valid systematic review, the methodology must be provided in as much detail as possible to ensure the repeatability of the search such as that subsequent attempts obtain the same results as the initial authors.
In Zweifel's systematic review, the methodological description was missing the PRISMA workflow, which provides the exact numbers of articles found, articles rejected (based on clear inclusion and exclusion criteria) after title and abstract review, articles rejected after full-text review, and articles retained in the final analysis [2]. Additionally, clear inclusion and exclusion criteria were missing [2]. The number of observers who performed the research was not included [2]. The search strategies along with the exact date (day, month, year) of the search were not provided [2]. The MeSH terms were also not provided [2]. All these elements indicate that the Zweifel review cannot be repeated by other authors. On the other hand, computed tomography (CT) scanning is a non-invasive imaging technique used to study ancient Egyptian artificially mummified human bodies. CT has been used for almost forty years [3]. The systematic review by Zweifel is not specifically related to CT scanning of mummies as it presents a general overview of this specific research field [2]. Therefore, we wanted to summarize the current knowledge on CT scanning of Egyptian artificially mummified bodies [4]. We also wanted to provide more valid methodology than that previously available. However, as this field seems too broad to be encapsulated in one global systematic review, we choose to focus on head and face CT scans of ancient Egyptian artificially mummified human remains.

Materials and methods

This systematic review was performed by one observer using two databases, PubMed (search equations n° 1 to n° 6) and EMBASE (search equation n° 7). The exclusion criteria were as follows: civilizations other than Egyptian, other archaeological periods of time; descriptions of ancient Egyptian mummies without heads; primary investigation technique other than CT (X-rays, MRI, endoscopy); chemistry, biochemistry, microbiology, parasitology, pathology, biomolecular and genetic studies (DNA studies, isotopes); description of a series of mummies without a clear distinction between individuals; no identification of the historical period of time for a given mummy; the description of a male mummy in a female coffin or a female mummy in male coffin; discordance of the date between the coffin and mummy [5]; experimental mummification; animal mummification; natural

mummification; reviews; and languages other than English and French. The inclusion criteria were as follows: description of ancient Egyptian artificial mummification using CT scan, the presence of description of the head, and English and French language. We used no time frame limitation (from 1948 to present). The article types accepted for this review consisted of case reports, case series, and comparative studies if it was possible to determine the individual characteristics for each of the individuals.

Search equation n° 1 ("teeth and ancient Egypt") was as follows: (("tooth"[MeSH Terms] OR "tooth"[All Fields]) OR ("tooth"[MeSH Terms] OR "tooth"[All Fields] OR "teeth"[All Fields])) OR ("dental health services"[MeSH Terms] OR ("dental"[All Fields] AND "health"[All Fields] AND "services"[All Fields]) OR "dental health services"[All Fields] OR "dental"[All Fields])) AND (ancient[All Fields] AND ("egypt"[MeSH Terms] OR "egypt"[All Fields])). The search was performed on 27/10/2016. We found 139 articles; 61 articles were excluded based on the title and abstract, 78 articles were included for a full-text review, and 8 articles were included for the final analysis after a full-text review. Articles with no abstract were also included in search equation n° 1.

Search equation n° 2 ("teeth and Egyptian mummy") was as follows: (egyptian[All Fields] AND ("mummies"[MeSH Terms] OR "mummies"[All Fields] OR "mummy"[All Fields]) AND ("tooth"[MeSH Terms] OR "tooth"[All Fields] OR "teeth"[All Fields])) AND hasabstract[text]. The search was performed on 13/10/2016, and we found 16 articles. Ten of the articles were excluded as duplicate articles from search equation n°1. We excluded 3 articles based on the title and abstract. Three articles were included for full-text review, and 2 articles were included for the final analysis after a full-text review.

Search equation n° 3 ("Egyptian and mummy and dentistry") was as follows: (egyptian[All Fields] AND ("mummies"[MeSH Terms] OR "mummies"[All Fields] OR "mummy"[All Fields]) AND ("dentistry"[MeSH Terms] OR "dentistry"[All Fields])) OR (egyptian[All Fields] AND ("mummies"[MeSH Terms] OR "mummies"[All Fields] OR "mummy"[All Fields]) AND ("dental health services"[MeSH Terms] OR ("dental"[All Fields] AND "health"[All Fields] AND "services"[All Fields]) OR "dental health services"[All Fields] OR "dental"[All Fields])) AND hasabstract[text]. The search was performed on 13/10/2016. We found 21 articles. There were 13 duplicate articles from previous search equations. Three articles were included for a full review, and finally 2 articles were selected for final study.

The search equation n° 4 ("Egyptian and mummies") was as follows: Egyptian[All Fields] AND ("mummies"[MeSH Terms] OR "mummies"[All Fields] OR "mummy"[All Fields]) AND hasabstract[text]. The search was performed on 13.10.2016, and 308 articles were found. Eighty-three of the articles without an abstract were excluded, and 90 articles with an abstract were excluded. There were 20 duplicate articles from previous search equations. There were 115 articles included for full-text review, and 17 articles were selected for the final analysis.

Search equation n° 5 ("mummy and CT scan") was as follows: "mummies"[MeSH Terms] OR "mummies"[All Fields] OR "mummy"[All Fields]) AND ("tomography,

x-ray computed"[MeSH Terms] OR ("tomography"[All Fields] AND "x-ray"[All Fields] AND "computed"[All Fields]) OR "x-ray computed tomography"[All Fields] OR ("computed"[All Fields] AND "tomography"[All Fields]) OR "computed tomography"[All Fields]) AND ("0001/01/01"[PDAT] : "2017/02/27"[PDAT]). The search was performed on 27/02/2017. There were 190 articles found. Thirty-nine of the articles without an abstract were excluded, and 82 articles with an abstract were excluded. There were 53 duplicate articles from previous search equations. Sixteen articles were included for full-text review, and 1 article was selected for final analysis.

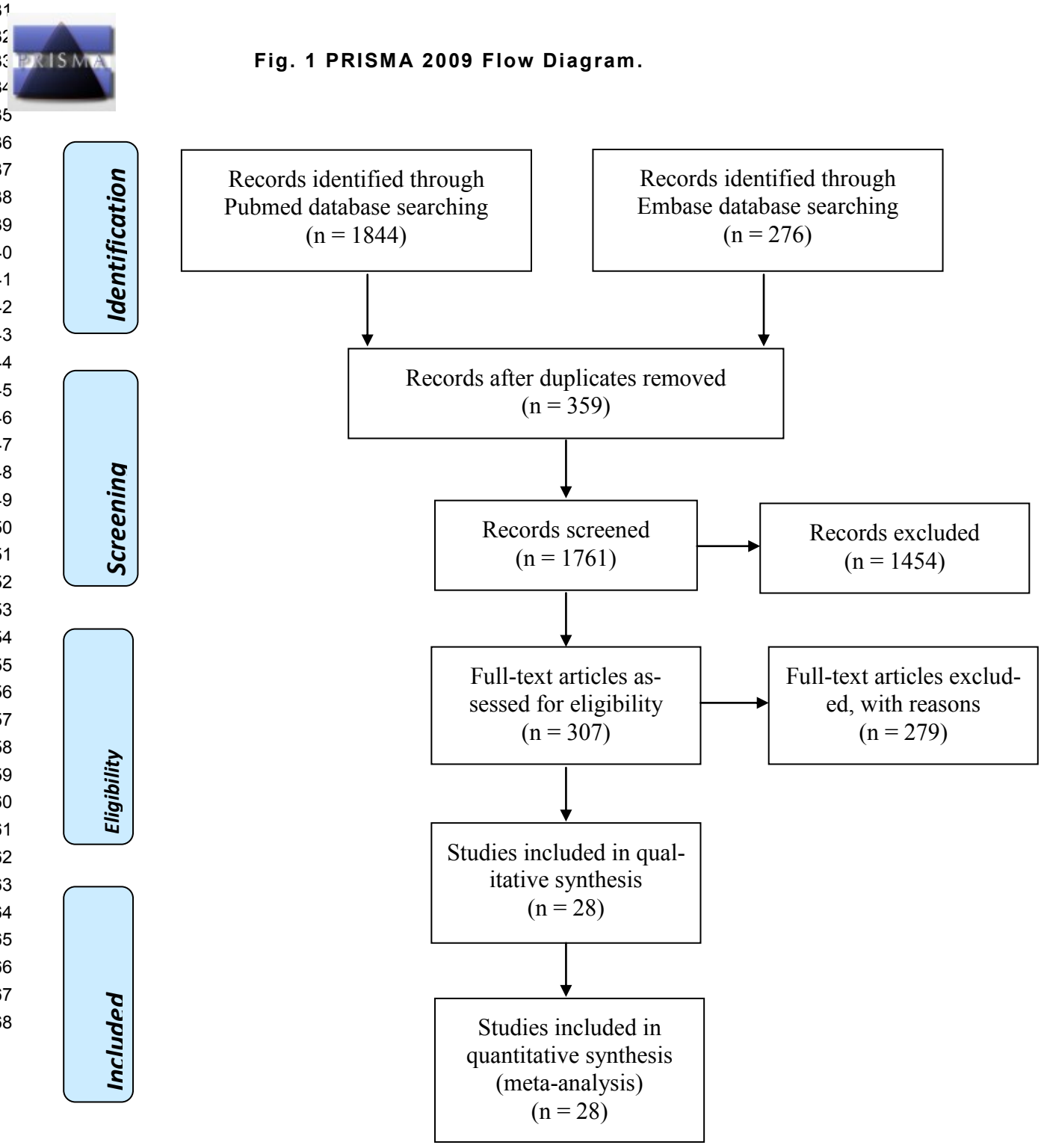
The search equation n° 6 ("mummy and human") was as follows: ("mummies"[MeSH Terms] OR "mummies"[All Fields] OR "mummy"[All Fields]) AND "humans"[MeSH Terms]. The search was performed on 16/11/2016. We found 1170 articles. In total, 433 articles without an abstract were excluded, and 532 articles with an abstract were excluded. There were 144 duplicate articles from previous search equations. Finally, 61 articles were included for a full-text review. All 61 of the articles were excluded, and no articles were selected for the final analysis.

The search equation n° 7 was performed on 28/10/2016 with the EMBASE database. The term 'paleopathology'/exp provided 2818 articles. The term 'computer assisted tomography'/exp provided 740,292 articles. The association of the terms 'paleopathology'/exp AND 'computer assisted tomography/exp' provided 276 articles. There were 119 articles that were duplicates of those identified from the PubMed database. A total of 126 articles were excluded based on the title and abstract. There were 31 articles included for a full-text review. The 31 articles were then excluded after a full-text review, and no articles were selected for the final analysis.

Finally, 2120 articles were found, 359 articles were duplicated among all search equations, 1454 articles were excluded, 307 articles were retained for a full-text review, and 28 articles were selected for the final analysis. We added a PRISMA flow diagram to better represent our findings (Figure 1).

Moreover, we proposed a simple score to compare the quality assessment of the reported CT data for each article selected for the review. The items receiving a score were as follows: tube intensity (kVp), tube current (mAs), slice thickness in mm, pitch, detector collimation, and reconstruction increment. If the item was described and cited it received one point, and if the item was missing it received no points. A score could vary from 0 (the minimum) to 6 (the maximum) for each CT-scanned mummy.

Fig. 1 PRISMA 2009 Flow Diagram.



Results

General information

The main information about the mummies is described in Table 1. There are 31 descriptions of CT findings related to individual artificial mummification of the head from ancient Egypt. Three cases were described by two different authors at different times: 1) Djedmaatesankh was described by Harwood-Nash in 1979 [3] and by Melcher in 1997 [6], 2) Tjentmutengebtiu described by Baldock in 1994 [7] and Hughes in 2005 [8], and 3) Se-Ankh (named so by the Memphis State Museum Director of Egyptology) was described by Singarella in 1986 [9], and Babin in 1990 [10]. We have not eliminated the duplicate reports to be able to study the differences in analyses performed by different scientific teams and authors.

There were 6 case series with 2 mummies and 19 case reports with one mummy description. The group consisted of 28 adults, 2 children and 1 adolescent. There were 15 males, 13 females, and 3 mummies of unknown sex. The supposed age was provided for 21 mummies and was undetermined or unknown in 10 individuals. The minimum age was 4 years, the maximum age was 60 years, and the average age was 38.88 years. The oldest described mummies in this study were from the Middle Kingdom (2040 BC), and the most recent were from the Roman period (110 AD). There were 3 mummies belonging to the Middle Kingdom, 3 mummies from the XVII Dynasty, 2 mummies from the XVIII Dynasty, 1 mummy from the End of the New Empire and the beginning of the 3rd intermediary period, 9 mummies from the XX-XXII Dynasty, 2 mummies from the XXV-XXVI Dynasties, 8 mummies from the Ptolemaic period, and 3 mummies from the Roman period. Mummies were found in museums in the following countries: 8 in the United States, 5 in Canada, 4 in the United Kingdom, 1 in Australia, 4 in Italy, 4 in Switzerland, 3 in Germany, 1 in Lithuania, and 1 in Vatican City.

Table 1. Information on selected studies.

Historical period	Study	Mummy name	Museum, Country, Inventory number (Inv)	Adult/ child	Sex	Age (years)
c. 2040-1674 BC (Middle Kingdom)	Yardley, 1997 [11] ROM1	NI	Royal Ontario Museum, Toronto, Canada	Adult	M	NI
c. 2040-1674 BC (Middle Kingdom)	Yardley, 1997 [11] ROM2	NI	Royal Ontario Museum, Toronto, Canada	Adult	M	NI
c. 2000 BC (Middle Kingdom)	Gupta, 2008 [12]	Djehutynakht (local governor of Middle Egyptian province)	Museum of Fine Arts, Boston, USA Inv. 21.11767	Adult	M	NI
c.1570-1520	Manley,	Qurna woman	National Muse-	Adult	F	20?

BC, (New Kingdom, XVII dyn)	2002 [13]		ums of Scotland, UK Inv. A.1909.527			
c.1570-1520 BC (XVII dyn)	Marquez, 2015 [14]	VL/1248	American Museum of Natural History, USA	Adult	NI	NI
c.1570-1520 BC (XVII dyn)	Marquez, 2015 [14]	VL/1232	American Museum of Natural History, USA	Adult	NI	NI
c.1479-1424 BC (XVIII dyn)	Wade, 2012 [15]	Theban female	Redpath Museum of McGill University, Canada Inv. RM2717	Adult	F	30-50 (40)
c.1479-1424 BC (XVIII dyn)	Bianucci, 2016 [16]	Nebiri ("Chief of stables")	Fondazione Museo delle Antichità Egizie, Torino, Italy Inv. S.5109 RCGE 17504	Adult	M	45-60 (52.5)
c.1150-795 BC (End New Empire-3rd intermediary period)	Lindsay, 2015 [17]	No name	Center for Evolutionary Medicine, Institute of Anatomy, University of Zurich, Switzerland	Adult	F	30-40 (35)
c.1069-945 BC (XXI dyn)	Brier, 2015 [18] (male)	Ankhefenmut, priest of the temple of the goddess Mut, and temple sculptor	Albany Institute of History and Art, USA Inv. 1909.18.1b	Adult	M	50-55 (52.5)
c.1069-747 BC (XXI –XXII dyn)	Hill, 1993 [19]	Bakt-en-Hor-Nekht	Hancock Museum, Newcastle-upon-Tyne, UK, Inv. Aregypt605	Adult	F	29
c.1069-747 BC (XXI-XXII dyn)	Gerloni, 2009 [20] (M2)	(Coffin Pa-sen-en-Hor), incense bear-er in the Amon tem-ple	Civic museum of history and art, Trieste, Italy, Inv. Cat.4.4	Adult	M	Middle-aged
c. 1000 BC (XXI dyn)	Wanek, 2011 [21]	NI	Musée d'Orbe, Switzerland	Adult	NI	NI
c. 1000-800 BC (XXI – XXII dyn)	Seiler, 2015 [22]	0492	Musée cantonal d'archéologie et d'histoire, Lausanne, Switzerland	Adult	M	NI

c.945-747 BC (XXII dyn)	Harwood-Nash, 1979 [3]	Djedmaatesankh (lady and musician of the House of Amun, Thebes)	Royal Ontario Museum, Toronto, Canada, Inv. 910.10 ROM2004_1039_9	Adult	F	NI
c.900 BC (XXII dyn)	Melcher, 1997 [6]	Djedmaatesankh (lady musician, Temple of Amun Re, Karnak)	Royal Ontario Museum, Toronto, Canada, Inv. 910.10 ROM2004_1039_9	Adult	F	Mature female
c.945-747 BC (XXII dyn)	Baldock, 1994 [7]	Tjentmutengebtiu	British Museum, London, UK, Inv. EA22939	Adult	F	19-23 (21)
c.770 BC (XXII dyn)	Hughes, 2005 [8]	Tjentmutengebtiu, priestess of temple in Karnak	British Museum, London, UK, Inv. Inv. EA22939	Adult	F	25-40 (32.5)
c.945-747 BC (XXI-XXIV dyn)	Cesarani, 2004 [23]	Harwa (artisan)	Egyptian Museum Torino, Italy, Inv. S. 5226/2 CGT 13011	Adult	M	45
c. 800-700 BC (XXII dyn)	Seiler, 2015 [22]	D242	Musée d'art et d'histoire, Genève, Switzerland	Adult	F	NI
c.746-525 BC (XXV-XXVI dyn)	Sigmund, 2002 [24]	Pa-es-tjau-em-aui-nu	Rheinische Landesmuseum, Trier, Germany, Inv. GIIC536	Adult	F	25?
c.600 BC (XXVI dyn)	Thekkaniyil, 2000 [25]	Lady Udja	Field Museum of natural History, Chicago, USA, Inv. 30001	Adult	M	30-40 (35)
Ptolemaic period	Singarella, 1986 [9]	No name	Private collection, Memphis, USA	Adult	F	30?
Ptolemaic period (323-30 BC)	Babin, 1990 [10]	Se-Ankh	Memphis State University, Egyptology collection, Memphis, USA	Adult	F	30-40 (35)
Ptolemaic period c.305-150 BC	Babin, 1990 [10]	Irtw-Irw	Memphis State University, Egyptology collection, Memphis, USA, Inv. 1985.3.1	Adult	M	60
Ptolemaic	Chan,	Akhmim	Academy of	Ado-	F	16?

period	2008 [26]		Natural Sciences, Philadelphia, USA, Inv. ANSP 1903.1a	lescent		
Ptolemaic period	Gerloni, 2009 [20] (M3)	NI	Civic museum of history and art, Trieste, Italy	Adult	M	NI
Ptolemaic period	Pelo, 2012 [27]	Fayoum female	Vatican Museum, Vatican	Adult	F	30
Ptolemaic period	Wade, 2012 [15]	Ptolemaic female	Redpath Museum of McGill University, Canada, Inv. RM2720	Adult	F	18-24 (21)
Ptolemaic period (323-30 BC)	Davey, 2013 [28]	Horus	Nicholson Museum, Sidney, Australia, Inv. NMR.26.1	Child	M	5-7 (6)
Ptolemaic period	Zesch, 2016 [29]	AS18	Senckenberg Museum of Natural History, Germany	Child	M	4 to 5 years-old (4.5)
100 BC-100 AD	Nickol, 1995 [30]	Mummy with the gilded cartonnage mask	Leipzig Ethnological Museum, Germany, Inv. MfVL 1965/33	Adult	F	25-30 (27.5)
Roman period (c.80-110 AD)	MacLeod, 2000 [31]	NI	National Museum of Scotland, Edinburgh, UK, Inv. A.1911.210.1	Adult	M	Young adult
Roman period (30 BC-395 AD	Piombino-Mascali, 2016 [32]	Hori, priest of Amun-Ra?	National Museum of Lithuania, Vilnus, Lithuania, Inv. IM6283	Adult	M	Young

NI: No information in the article

Principal authors affiliation

Authors affiliations are described in Table 2. The main affiliations and expertise of the authors were as follows: 1) radiology (18/28, 64.2%), 2) Egyptology museum (17/28, 60.7%), 3) anthropology (7/28, 25%), 4) dentistry (7/28, 25%), 5) ear-nose-throat (3/28, 10.7%), and 6) other type of affiliation (12/28, 42.8%). Multidisciplinary teams including members with radiology, Egyptology, and dentistry expertise were rare (3/28, 10.7%).

310 **Table 2.** Principal author's affiliations.

Study	Radiology	Museum (Egyptology)	Physical anthropology (forensic)	Dentistry	Ear-nose-throat	Other
Harwood-Nash, 1979 [3]	YES					
Singarella, 1986 [9]						Education development
Babin, 1990 [10]		YES			YES	
Hill, 1993 [19]		YES		YES		
Baldock, 1994 [7]	YES	YES		YES		Neurosurgery
Nickol, 1995 [30]	YES	YES				Medical history
Melcher, 1997 [6]	YES			YES		Pediatrics
Yardley, 1997 [11]					YES	
MacLeod, 2000 [31]	YES	YES		YES (oral medicine, orthodontics)		
Thekkaniyil, 2000 [25]				YES (orthodontics)		
Sigmund, 2002 [24]	YES	YES				
Manley, 2002 [13]		YES				Medical artist
Cesarani, 2004 [23]	YES	YES	YES			
Hughes, 2005 [8]		YES				Physical and chemical science, computer centre
Chan, 2008 [26]	YES	YES				
Gupta, 2008 [12]	YES	YES				neurosurgery
Gerloni, 2009 [20]	YES		YES	YES		
Wanek, 2011 [21]						Evolutionary medicine, computer vision lab
Wade, 2012 [15]	YES	YES	YES			
Pelo, 2012 [27]	YES	YES		YES (maxillofacial sur-		

				gery, orthodontics)		
Davey, 2013 [28]	YES		YES			
Lindsay, 2015 [17]			YES			Art applied to medicine, evolutionary medicine
Marquez, 2015 [14]	YES	YES			YES	
Brier, 2015 (male) [18]	YES					
Seiler, 2015 [22]						Evolutionary medicine
Bianucci, 2016 [16]	YES	YES	YES			Microbiology and infectiology
Zesch, 2016 [29]	YES	YES				Biomechanics
Piombino-Mascali, 2016 [32]	YES	YES	YES			

Computer tomography radiological protocol

The radiological protocols provided for each mummy are described in Table 3. The maximum score for the quality of the reported CT radiological protocol was reached in only 1 case (in the most recent study). Two cases obtained a score of 5, 2 cases obtained a score of 4, 10 cases obtained a score of 3, 5 cases obtained a score of 2, 8 cases obtained a score of 1 (only slice thickness was provided), and 6 studies obtained a score of 0. The kVp was provided for 20 mummies, mAs for 17 mummies, slice thickness for 26 mummies, pitch for 3 mummies, detector collimation for 1 mummy (in the most recent study), and reconstruction increment for 5 mummies. The three items most frequently provided together were kvp, mAs, and slice thickness (15 mummies).

Table 3. Computed tomography radiological protocols.

Study	**CT type**	**Score (0-6) (Index of quality of reporting of CT protocol)**	**Tube voltage (kVp)**	**Tube current (mAs)**	**Slice thickness (mm)**	**Pitch (mm/sec)**	**Detector collimation**	**Reconstruction increment (mm)**
Harwood-Nash, 1979 [3]	Ohio Nuclear Delta 50	1	NI	NI	12	NI	NI	NI

Singarella 1986 [9]	CAT scan	0	NI	NI	NI	NI	NI	NI
Babin 1990 (Se-Anh) [10]	Siemens DR3	1	NI	NI	4 mm skull, 2 mm temporal bone	NI	NI	NI
Babin 1990 (Iret-Irew) [10]	Siemens DR3	1	NI	NI	4 mm skull, 2 mm temporal bone	NI	NI	NI
Hill 1993 [19]	CT	1	NI	NI	5mm	NI	NI	NI
Baldock 1994 [7]	Somatom DRH, Siemens	1	NI	NI	2 mm skull, 1 mm teeth	NI	NI	NI
Nickol 1995 [30]	Somaton plus, Siemens	2	120	125	NI	NI	NI	NI
Yardley 1997 (ROM I) [11]	CT	1	NI	NI	1.5 mm	NI	NI	NI
Yardley 1997 (ROM II) [11]	CT	1	NI	NI	1.5mm	NI	NI	NI
Melcher 1997 [6]	9800 Quick scanner, GE	3	120	170	3mm with 3mm spacing	NI	NI	NI
Macleod 2000 [31]	Somatom plus, Siemens	5	120	210	3	3	NI	1
Thekkaniyil 2000 [25]	CT	0	NI	NI	NI	NI	NI	NI
Manley 2002 [13]	CT	0	NI	NI	NI	NI	NI	NI
Sigmund 2002 [24]	Somatom Plus 4A, Siemens	0	NI	NI	NI	NI	NI	NI
Cesarani 2004 [23]	LightSpeed QX/i, GE Healthcare	5	120	140	1.25	7.5	NI	0.7
Hughes 2005 [8]	DRH Somaton, Siemens	3	125	210	2	NI	NI	NI
Chan 2008 [26]	Lightspeed 16, GE	3	140	275	0.625	NI	NI	NI
Gupta 2008 [12]	Sensation-64, Siemens	2	120	50	NI	NI	NI	NI

Gerloni 2009 (M2) [20]	Aquilion 16, Toshiba	3	120	300	0.5	NI	NI	NI
Gerloni 2009 (M3) [20]	Aquilion 16, Toshiba	3	120	300	0.5	NI	NI	NI
Wanek 2011 [21]	Somatom definition dual source, CT_SOM5 SPI DU-AL, Siemens	4	140 and 100	27 and 120	0.6	NI	NI	0.4
Wade 2012 (2717) [15]	Aquilion one, Toshiba	2	120	NI	0.5	NI	NI	NI
Wade 2012 (2720) [15]	Aquilion one, Toshiba	2	80 and 135	NI	0.5	NI	NI	NI
Pelo 2012 [27]	Brillance CT 64-channel, Phillips	4	120	150	1	NI	NI	0.5
Davey, 2013 [28]	Aquilon 64, Toshiba	3	120	150	0.5	NI	NI	NI
Seiler 2015 (0492) [22]	NI	0	NI	NI	NI	NI	NI	NI
Seiler 2015 (D242) [22]	NI	0	NI	NI	NI	NI	NI	NI
Lindsay 2015 [17]	NI	3	100	49	0.2	NI	NI	NI
Marquez 2015 VL1248 [14]	High speed Ad-vantage CT, GE	3	120	250	1	NI	NI	NI
Marquez 2015 VL1232 [14]	High speed Ad-vantage CT, GE	3	120	250	1	NI	NI	NI
Brier 2015 (male) [18]	Light speed 16-slice CT, GE	2	120	NI	0.6	NI	NI	NI
Piombino-Mascali 2016 [32]	Brillance 16-slice, Phillips	3	120	215	1	NI	NI	NI
Bianucci	MDCT	1	NI	NI	0.4	NI	NI	NI

2016 [16]	Brillance 16, Phillips							
Zesch 2016 [29]	Dual energy	6	140/80	80/110	0.6	0.55	2x32x0.6	0.3

NI : No information in the article

Excerebration pathways

Different types of excerebration pathways are presented in Table 4. Nasal bone fractures were present in 15 mummies, they were absent in 5 mummies, and no information was provided in 11 mummies. The nasal septum deviates to the side opposite the excerebration pathway. Ethmoid bone fractures were present in 19 cases, with no fractures in 5 cases and no information provided in 7 cases. Most ethmoid bone fractures were on the left side (6/19, 31.5%), or were bilateral (5/19, 26.3%). A right ethmoid bone fracture was described in few cases (2/19, 10.5%). However, there were also some cases with no side indication (7/19, 36.8%). The sphenoid bone was fractured in 4 cases, with no fracture in 11 cases, and no information provided for 16 cases. Sphenoid fractures are always associated with ethmoid fractures and represent a posterior extension of the ethmoidal excerebration pathway. Perforation of the thin walls of the orbit (medial wall, roof) was described in 3 cases. The fractures of orbital walls were present on the same side as the ethmoid bone fracture.

Table 4. Brain excerebration pathways.

Historical period	Study	Sex M/F	Nasal bone fracture	Ethmoid bone fracture	Sphenoid bone fracture	Other fractures
2040-1674 BC (Middle Kingdom)	Yardley 1997 (ROM I) [11]	M	YES	YES, bilateral	NO	NO
2040-1674 BC (Middle Kingdom)	Yardley 1997 (ROM II) [11]	M	YES	YES, bilateral	NO	NO
2000 BC (Middle Kingdom)	Gupta 2008 [12]	M	YES septum	YES, left	NO	occipital foramen left , bilateral coronoid process-mandible, zygomatic bone-bilateral, anterior wall maxillary sinus-bilateral, left styloid process excised
c.1570-1520 BC (XVII dyn)	Manley 2002 [13]	F	NI	NI	NI	NI
c.1570-1520 BC (XVII	Marquez 2015	NI	YES	YES, bilateral	NO	NO

dyn)	(VL1248) [14]					
c.1570-1520 BC (XVII dyn)	Marquez 2015 (VL1232) [14]	NI	YES	YES	NI	NI
c.1479-1424 BC (XVIII dyn)	Wade 2012 [15]	F	NO	NO	NO	NO
c.1479-1424 BC (XVIII dyn)	Bianucci 2016 [16]	M	NO	NO	NO	NO
c.1150-795 BC (End New Empire-3rd intermediary period)	Lindsay 2015 [17]	F	YES, left	YES, left	YES, left	Medial wall of left orbit, parietal bone right (1 hole) and left (1 hole)
c.1069-945 BC (XXI dyn)	Brier 2015 [18]	M	YES	YES, bilateral	NI	NI
c.1069-747 BC (XXI –XXII dyn)	Hill 1993 [19]	F	YES	NI	NI	Upper orbit, right
c.1069-747 BC (XXI-XXII dyn)	Gerloni 2009 (M2) [20]	M	NI	YES	YES	NI
c. 1000 BC (XXI dyn)	Wanek 2011 [21]	NI	NI	YES, left	NI	NI
c. 1000-800 BC (XXI – XXII dyn)	Seiler 2015 (0492) [22]	M	NI	NI	NI	NI
c.945-747 BC (XXII dyn)	Harwood-Nash 1979 [3]	F	NI	YES, left	NI	NI
c.900 BC (XXII dyn)	Melcher 1997 [6]	F	NI	NI	NI	NI
c.945-747 BC (XXII dyn)	Baldock 1994 [7]	F	YES	YES	NI	NI
c.770 BC (XXII dyn)	Hughes 2005 [8]	F	NI	NI	NI	NI
c.945-747 BC (XXI-XXIV dyn)	Cesarani 2004 [23]	M	NI	YES	NI	NI
c. 800-700 BC (XXII	Seiler 2015 (D242) [22]	F	NI	NI	NI	Parietal bone, right

dyn)						
c.746-525 BC (XXV-XXVI dyn)	Sigmund 2002 [24]	F	NO	NO (great occipital foramen)	NO	NO
c.600 BC (XXVI dyn)	Thekkaniyil, 2000 [25]	M	YES	NI	NI	NI
Ptolemaic period	Singarella 1986 [9]	F	NI	NI	NI	NI
Ptolemaic period (323-30 BC)	Babin 1990 (Se-Anht) [10]	F	NI	YES, left	NI	NO
Ptolemaic period c.305-150 BC	Babin 1990 (Irtw-Irw) [10]	M	YES, septum deviated to left	YES, bi-lateral	NI	NO
Ptolemaic period	Chan, 2008 [26]	F	NI	YES, right	YES, right	NI
Ptolemaic period	Gerloni, 2009 (M3) [20]	M	NI	YES	NI	NI
Ptolemaic period	Pelo, 2012 [27]	F	NI	NI	NI	NI
Ptolemaic period	Wade, 2012 [15]	F	YES	YES, right	YES, right	NO
Ptolemaic period (323-30 BC)	Davey, 2013 [28]	M	YES, septum deviated to the right	YES, left	NO	NO
Ptolemaic period	Zesch, 2016 [29]	M	NO	NO	NO	NO
100 BC-100 AD	Nickol, 1995 [30]	F	YES	YES	NI	NI
Roman period (c.80-110 AD)	MacLeod, 2000 [31]	M	NO	NO (great occipital foramen)	NO	NO
Roman period (30 BC-395 AD	Piombino-Mascali, 2016 [32]	M	YES, right	NI	NO	Frontal roof of right orbit

NI : No information in the article

When looking at the historical period, and the type of excerebration pathway (Table 4), ethmoid left and ethmoid bilateral pathways are the oldest pathways described in this study (from the Middle Kingdom) [11, 12].

The ethmoid with sphenoid extension pathway, and the ethmoid and orbit extension pathway appeared in this study at the end of New Empire and beginning of the 3rd intermediary period [17]. The right ethmoid bone pathway appears in this study in the Ptolemaic period [26]. We also found 2 cases of excerebration through the great occipital foramen from the XXV-XXVI Dynasty [24].

Table 5 provides information about the relationship between sex and skull fractures associated with excerebration pathways. The small sample in this study did not allow us to perform any statistical analyses. However, sphenoid extension pathways are more common in female mummies.

Table 5. Relationship between sex and excerebration pathways.

Fracture	Nasal bone	Ethmoid bone	Sphenoid bone
Male/Female	8/5	9/7	1/3

Table 6 provides information about excerebration and brain content. Full excerebration was described in 19 cases. It appeared in this study in mummies from the Middle Kingdom [11]. Partial excerebration was present in 4 cases (from the XVII Dynasty). No excerebration was found in 3 cases (from the XVIII Dynasty), and no information was provided in 5 cases.

Table 6. Excerebration and brain content.

Historical period	Study	Gender M/F	Excerebration	Foreign objects in skull	Brain	Dura mater	Dura cervical
2040-1674 BC (Middle Kingdom)	Yardley 1997 (ROM I) [11]	M	YES	NI	NO	NI	NI
2040-1674 BC (Middle Kingdom)	Yardley 1997 (ROM II) [11]	M	YES	NI	NO	NI	NI
2000 BC (Middle Kingdom)	Gupta 2008 [12]	M	YES	NO	NO	NO	NO
c.1570-1520 BC (XVII dyn)	Manley 2002 [13]	F	NI	NI	NI	NI	NI
c.1570-1520 BC (XVII dyn)	Marquez 2015 (VL1248) [14]	NI	YES	YES, resin (occipital)	YES, fragments	YES	YES
c.1570-1520 BC (XVII dyn)	Marquez 2015 (VL1232) [14]	NI	YES	NI	NI	NI	NI
c.1479-1424 BC (XVIII dyn)	Wade 2012 [15]	F	NO	NO	YES	YES	YES

c.1479-1424 BC (XVIII dyn)	Bianucci 2016 [16]	M	NO	NO	YES	YES	NI
c.1150-795 BC (End New Empire-3rd intermediary period)	Lindsay 2015 [17]	F	YES	YES, resin (occipital)	NO	NO	NO
c.1069-945 BC (XXI dyn)	Brier 2015 [18]	M	YES	YES, resin (occipital, parietal right)	NO	NI	NI
c.1069-747 BC (XXI –XXII dyn)	Hill 1993 [19]	F	YES	NI	NI	NI	NI
c.1069-747 BC (XXI-XXII dyn)	Gerloni 2009 (M2) [20]	M	YES	YES, resin-soaked linen bandages	NO	NI	NI
c. 1000 BC (XXI dyn)	Wanek 2011 [21]	NI	YES	YES, resin (occipital)	NO	NO	NO
c. 1000-800 BC (XXI – XXII dyn)	Seiler 2015 (0492) [22]	M	NI	NI	NI	NI	NI
c.945-747 BC (XXII dyn)	Harwood-Nash 1979 [3]	F	YES	NO	NO meningeal linings	YES	NI
c.900 BC (XXII dyn)	Melcher 1997 [6]	F	NI	NI	NI	NI	NI
c.945-747 BC (XXII dyn)	Baldock 1994 [7]	F	YES	YES, linen	NO	NI	NI
c.770 BC (XXII dyn)	Hughes 2005 [8]	F	YES	NI	NO	YES	NI
c.945-747 BC (XXI-XXIV dyn)	Cesarani 2004 [23]	M	YES	NI	NO	YES	NI
c. 800-700 BC (XXII dyn)	Seiler 2015 (D242) [22]	F	YES	YES, resin (parietal, occipital, occipital path	NO	NI	NI

				flow), 2 teeth			
c.746-525 BC (XXV-XXVI dyn)	Sigmund 2002 [24]	F	YES	YES, resin (occipital)	NO	NO	NO
c.600 BC (XXVI dyn)	Thekkaniyil, 2000 [25]	M	YES	YES, embalming residu (occipital)	YES, fragments	NI	NI
Ptolemaic period	Singarella 1986 [9]	F	YES	NI	NI	NI	NI
Ptolemaic period (323-30 BC)	Babin 1990 (Se-Anht) [10]	F	YES	YES, resin (occipital),Insects larvae (endoscope)	NO	NO	NO
Ptolemaic period c.305-150 BC	Babin 1990 (Irtw-Irw) [10]	M	YES	YES, resin (occipital), left frontal sinus, right maxillary sinus, foramen magnum, Insects larvae (endoscope)	NO	NO	NI
Ptolemaic period	Chan, 2008 [26]	F	YES	YES, resin	NO	NI	NI
Ptolemaic period	Gerloni, 2009 (M3) [20]	M	YES	NI	YES, brain fragments, meningeal linings	YES	NI
Ptolemaic period	Pelo, 2012 [27]	F	NI	NI	NI	NI	NOI
Ptolemaic period	Wade, 2012 [15]	F	YES	YES, resin (occipital, 3 path flows) Resin in right ethmoid	NO	NO	YES

				sinus, in left maxillary sinus, 5 bone fragments (3 in resin, 2 in cervical area), 3 fragments of wood			
Ptolemaic period (323-30 BC)	Davey, 2013 [28]	M	YES	NO	NO	NO	YES
Ptolemaic period	Zesch, 2016 [29]	M	NO	NO	YES	YES	YES
100 BC-100 AD	Nickol, 1995 [30]	F	YES	YES, linen	NO	NI	NOI
Roman period (c.80-110 AD)	MacLeod, 2000 [31]	M	YES	YES, embalming residue (upper cervical spine)	NO	NO	YES
Roman period (30 BC-395 AD	Piombino-Mascali, 2016 [32]	M	YES	NO	NO	NO	NI

The skull was empty in 7 cases. Resin was found in the skull in 10 cases (from the XVII Dynasty), resin and linen bandages in 1 case (from XXI-XXII Dynasty), linen in 2 cases (from the XXII Dynasty), embalming material in 2 cases (from the XXVI Dynasty), and no information was provided for 9 cases.
Resin was present in the occipital area in 9 cases (from the XVII Dynasty), in the occipital and parietal areas in 2 cases (from the XXI Dynasty), and outside of the brain in the maxillary sinus in 2 cases (from the Ptolemaic period). There were also two exceptional cases (from one study) from the Ptolemaic period with the presence of larval insects inside the skull [10]. There seems to be no relationship between sex and brain content in this study sample.

Soft tissue preservation

Table 7 provides information regarding the preservation of soft facial tissues. The ears were present in 15 cases, and no information was provided for 16 cases. Three

mummy descriptions gave no information about the preservation of any type of soft tissue of the face and skull. The eye globes were present in 15 cases (all historical periods). There were 2 cases of one missing eye (from the Middle Kingdom). There were 17 cases with no description of the eye globe preservation state. Both eye globes were missing in two cases (XXI Dynasty). Eye muscles were preserved in 10 cases, with no information provided in 20 cases. In one case all the orbit content was absent including eye globes, eye muscles and the optic nerves [20]. Optic nerves were present in 8 cases, they were absent in 2 cases, and no information was provided for 21 cases. The tongue was present in 12 cases (all historical periods), and no information was provided for 19 cases.

Table 7. Preservation of facial soft tissues.

Historical period	Study	Sex M/F	Ears	Eye globe	Eye muscles	Optic nerve	Tongue
2040-1674 BC (Middle Kingdom)	Yardley 1997 (ROM I) [11]	M	NOI	YES, left	NOI	NOI	NOI
2040-1674 BC (Middle Kingdom)	Yardley 1997 (ROM II) [11]	M	NOI	YES, left	NOI	NOI	NOI
2000 BC (Middle Kingdom)	Gupta 2008 [12]	M	NOI	NOI	NOI	NOI	NOI
c.1570-1520 BC (XVII dyn)	Manley 2002 [13]	F	NOI	NOI	NOI	NOI	NOI
c.1570-1520 BC (XVII dyn)	Marquez 2015 (VL1248) [14]	NI	YES	NOI	NOI	NOI	YES
c.1570-1520 BC (XVII dyn)	Marquez 2015 (VL1232) [14]	NI	YES	NOI	NOI	NOI	NOI
c.1479-1424 BC (XVIII dyn)	Wade 2012 (RM2717) [15]	F	NOI	NOI	NOI	NOI	NOI
c.1479-1424 BC (XVIII dyn)	Bianucci 2016 [16]	M	YES	YES	NOI	NOI	NOI
c.1150-795 BC (End New Empire-3rd intermediary period)	Lindsay 2015 [17]	F	YES	YES	YES	NOI	YES
c.1069-945 BC (XXI dyn)	Brier 2015 (male) [18]	M	NOI	YES	YES	YES	YES

c.1069-747 BC (XXI –XXII dyn)	Hill 1993 [19]	F	NOI	NOI	NOI	NOI	NOI
c.1069-747 BC (XXI-XXII dyn)	Gerloni 2009 (M2) [20]	M	NOI	NO	NO	NO	NOI
c. 1000 BC (XXI dyn)	Wanek 2011 [21]	NI	NOI	YES	YES	NOI	YES
c. 1000-800 BC (XXI – XXII dyn)	Seiler 2015 (0492) [22]	M	YES	NOI	NOI	NOI	YES
c.945-747 BC (XXII dyn)	Harwood-Nash, 1979 [3]	F	NOI	YES	YES	YES	NOI
c.900 BC (XXII dyn)	Melcher 1997 [6]	F	NOI	NOI	NOI	NOI	NOI
c.945-747 BC (XXII dyn)	Baldock 1994 [7]	F	YES	NO	NO	NO	NOI
c.770 BC (XXII dyn)	Hughes 2005 [8]	F	YES	YES	YES	NOI	NOI
c.945-747 BC (XXI-XXIV dyn)	Cesarani 2004 [23]	M	YES	NOI	NOI	NOI	NOI
c. 800-700 BC (XXII dyn)	Seiler 2015 (D242) [22]	F	YES	NOI	NOI	NOI	YES
c.746-525 BC (XXV-XXVI dyn)	Sigmund 2002 [24]	F	YES	YES	YES	YES	YES
c.600 BC (XXVI dyn)	Thekkaniyil 2000 [25]	M	NOI	NOI	NOI	NOI	NOI
Ptolemaic period	Singarella 1986 [9]	F	NOI	NOI	NOI	NOI	NOI
Ptolemaic period (323-30 BC)	Babin 1990 (Se-Anht) [10]	F	YES	YES	YES	YES	NOI
Ptolemaic period c.305-150 BC	Babin 1990 (Irt-Irw) [10]	M	YES (protu-berant position of ears due to linen wrap-ping)	YES	YES	YES	NOI
Ptolemaic period	Chan 2008 [26]	F	NOI	NOI	NOI	NOI	NOI
Ptolemaic period	Gerloni 2009 (M3) [20]	M	NOI	NOI	NOI	NOI	NOI
Ptolemaic period	Pelo 2012 [27]	F	NOI	NOI	NOI	NOI	NOI
Ptolemaic period	Wade 2012 (RM2720)	F	NOI	YES	NOI	NOI	NOI

	[15]						
Ptolemaic period (323-30 BC)	Davey, 2013 [28]	M	YES	NOI	NOI	NOI	YES
Ptolemaic period	Zesch 2016 [29]	M	YES	YES	YES	YES	YES
100 BC-100 AD	Nickol 1995 [30]	F	NOI	NOI	NOI	NOI	YES
Roman period (c.80-110 AD)	MacLeod 2000 [31]	M	YES	YES	YES	YES	YES
Roman period (30 BC-395 AD	Piombino-Mascali 2016 [32]	M	YES	YES	NOI	YES	YES

NOI: not interpretable from article and/or from CT image presented in the article

Information about brain excerebration is provided in Table 4. We also wanted to know how often the excerebration was associated with the removal of the dura mater and/or the dura cervical (Table 6). The dura mater was present in 8 cases, it was absent in 10 cases, and no information was given in 13 cases. The combination of an absent brain with the dura mater present appeared in 3 cases (from the XXII Dynasty). The combination of the absent brain with the dura mater absent was observed in 10 cases (all historical periods). The dura cervical was present in 6 cases, it was absent in 5 cases, and no information was provided in 20 cases. The combination of absent brain, absent dura mater, and absent dura cervical was present in 5 cases (all historical periods). The combination of absent brain, absent dura mater, and present dura cervical appeared in 3 cases (from the Ptolemaic period). We could not find any correlation between sex and facial soft tissue preservation due to incomplete data in the selected articles.

Dental status

Table 8 provides information about the different types of CT examinations used to study the dental status of Egyptian mummies. The teeth were evaluated with different CT scanning modalities, such as two-dimensional (2D) CT slices (8 cases), 2D multiplanar reconstructions (MR) mimicking dental panoramic imaging (4 cases), three-dimensional (3D) skull reconstructions (13 cases), and 2D and 3D approaches (6 cases). A combination of techniques with 2D, 3D, and 2D MR was used in two cases. No information on the CT modality used was provided for one case. The visualization and interpretation of the dental status was possible in 21 cases, especially when the multiplanar reconstruction of dental arches was provided. The visualization and interpretation of the dental status was impossible in 10 cases because of a field of view excluding the teeth or low-quality 3D CT reconstruction of the dental arches. In those cases, only 2D and/or 3D imaging was provided.

Table 8. Teeth visualization using CT scans.

Historical period	Study	Head CT modality	Teeth visualized on CT images in the article
2040-1674 BC (Middle Kingdom)	Yardley 1997, (ROM I) [11]	2D	NO
2040-1674 BC (Middle Kingdom)	Yardley 1997, (ROM II) [11]	2D	NO
2000 BC (Middle Kingdom)	Gupta 2008 [12]	2D, 3D	YES
c.1570-1520 BC (XVII dyn)	Manley 2002 [13]	3D	YES
c.1570-1520 BC (XVII dyn)	Marquez 2015 (VL1248) [14]	2D, 3D	NO
c.1570-1520 BC (XVII dyn)	Marquez 2015 (VL1232) [14]	2D	NO
c.1479-1424 BC (XVIII dyn)	Wade 2012 (RM2717) [15]	3D	NO
c.1479-1424 BC (XVIII dyn)	Bianucci 2016 [16]	2D, MR	YES
c.1150-795 BC (End New Empire-3rd intermedi-ary period)	Lindsay 2015 [17]	2D, 3D	YES
c.1069-945 BC (XXI dyn)	Brier 2015 (male) [18]	2D	NO
c.1069-747 BC (XXI –XXII dyn)	Hill 1993 [19]	3D (low quality)	YES
c.1069-747 BC (XXI-XXII dyn)	Gerloni 2009 (M2) [20]	2D, MR	YES
c. 1000 BC (XXI dyn)	Wanek 2011 [21]	3D	YES
c. 1000-800 BC	Seiler 2016 (0492) [22]	2D, MR	YES

(XXI – XXII dyn)			
c.945-747 BC (XXII dyn)	Harwood-Nash, 1979 [3]	2D	NI
c.900 BC (XXII dyn)	Melcher 1997 [6]	3D, 2D MR low quality	YES
c.945-747 BC (XXII dyn)	Baldock 1994 [7]	3D	NI
c.770 BC (XXII dyn)	Hughes 2005 [8]	2D, 3D	NO
c.945-747 BC (XXI-XXIV dyn)	Cesarani 2004 [23]	3D	YES
c. 800-700 BC (XXII dyn)	Seiler 2015 (D242) [22]	2D, MR	YES
c.746-525 BC (XXV-XXVI dyn)	Sigmund 2002 [24]	3D	YES
c.600 BC (XXVI dyn)	Thekkaniyil 2000 [25]	3D, 2D MR low quality	YES
Ptolemaic period	Singarella 1986 [9]	NI	NO
Ptolemaic period (323-30 BC)	Babin 1990 (Se-Anht) [10]	2D	NO
Ptolemaic period c.305-150 BC	Babin 1990 (Iret-Irew) [10]	2D	NO
Ptolemaic period	Chan 2008 [26]	2D	YES
Ptolemaic period	Gerloni 2009 (M3) [20]	3D	YES
Ptolemaic period	Pelo 2012 [27]	3D	YES
Ptolemaic period	Wade 2012 (RM2720) [15]	3D	NO
Ptolemaic period (323-30 BC)	Davey, 2013 [28]	2D, 3D	YES

Ptolemaic period	Zesch 2016 [29]	3D teeth reconstruction	YES
100 BC-100 AD	Nickol 1995 [30]	2D, 3D	YES
Roman period (c.80-110 AD)	Macleod 2000 [31]	3D	YES
Roman period (30 BC-395 AD	Piombino-Mascali 2016 [32]	3D	YES

NI: no information in the article
MR: multiplanar reconstruction

Table 9 provides information about the dental status of the mummies. The dentition type was definitive in 29 mummies, mixed in one mummy, and lacteal in another mummy. All 32 teeth were present in 10 cases. Missing teeth were observed in 11 cases, and no information was provided for 10 cases. Missing teeth were not related to any specific period in history. The teeth were missing in 8 cases on the maxilla and in 10 cases on the mandible. Most of the missing teeth were molars (10 cases), premolars (4 cases), incisors (4 cases), and canines (2 cases). Fractured teeth were present in 5 cases (from the end of the New Empire-to the beginning of the 3rd intermediary period), they were absent in 17 cases, and no information was provided for 9 cases. Fractured teeth were only found on the maxilla and were mostly incisors (4 cases out of 5). Tooth wear was present in this study in 18 cases (all historical periods), it was absent in 5 cases, and no information was provided in 8 cases. No tooth wear and a full dentition were present in this study in 3 cases from the Ptolemaic and Roman times. Periapical lesions represented by an empty space around the apex of a tooth root were present in this study in 10 cases (from the XVIII Dynasty), they were absent in 7 cases, and no information was provided in 14 cases. Caries were present in this study in 7 cases (from the XVII Dynasty), they were absent in 9 cases, and no information was available in 15 cases.

Table 9. Dental status of the mummies.

Historical period	**Study**	**Sex M/F**	**Dentition type (L-lacteal, M-mixt, D-definitive)**	**Teeth missing**	**Teeth fractured**	**Wear**	**Periapical lesion (IDF tooth number)**	**Caries**
2040-1674 BC (Middle Kingdom)	Yardley 1997, (ROM I) [11]	M	D	NI	NI	YES	NI	NI
2040-1674 BC (Middle	Yardley 1997, (ROM II) [11]	M	D	NI	NI	YES	NI	NI

Kingdom)								
2000 BC (Middle Kingdom)	Gupta 2008 [12]	M	D	48, 18, 17, 16, 26, 27, 28	NO	YES	NO	NI
c.1570-1520 BC (XVII dyn)	Manley 2002 [13]	F	D	NI	NI	NO	NI	YES
c.1570-1520 BC (XVII dyn)	Marquez 2015 (VL1248) [14]	NI	D	NO	NO	NI	NI	NI
c.1570-1520 BC (XVII dyn)	Marquez 2015 (VL1232) [14]	NI	D	27, 38, 47	NO	NI	NI	NI
c.1479-1424 BC (XVIII dyn)	Wade 2012 (RM2717) [15]	F	D	12 to 18, 23 to 28, 45 to 48, 34 to 38	NO	YES	21, 22, 31, 32, 33, 42, 43, 44	YES, 43
c.1479-1424 BC (XVIII dyn)	Bianucci 2016 [16]	M	D	18, 23, 27, 28	NO	YES	11, 12, 13, 14, 15, 21, 22, 24, 31, 46	NO
c.1150-795 BC (End New Empire-3rd intermedi-ary period)	Lindsay 2015 [17]	F	D	NO	11, 21	YES	NI	NI
c.1069-945 BC (XXI dyn)	Brier 2015 (male) [18]	M	D	NO	NO	NI	NO	NO
c.1069-747 BC (XXI –XXII dyn)	Hill 1993 [19]	F	D	NI	NI	NI	NI	NI
c.1069-747 BC (XXI-XXII dyn)	Gerloni 2009 (M2) [20]	M	D	NO	NO	YES	11, 15, 25	YES, 15, 16
c. 1000 BC (XXI dyn)	Wanek 2011 [21]	NI	D	NI	NI	NI	NI	NI
c. 1000-800 BC (XXI – XXII dyn)	Seiler 2016 (0492) [22]	M	D	41, 42, 46, 47, 31, 35, 36	NI	YES	NI	NI
c.945-747 BC (XXII dyn)	Harwood-Nash, 1979 [3]	F	D	NI	NI	NI	NI	NI

c.900 BC (XXII dyn)	Melcher 1997 [6]	F	D	18, 37, 38	24	YES	11, 12, 14, 15, 16, 21, 22, 23, 24, 25, 26, 34, 35, 36, 45, 46, 47, 48	NI
c.945-747 BC (XXII dyn)	Baldock 1994 [7]	F	D	NI	NI	YES	NI	NI
c.770 BC (XXII dyn)	Hughes 2005 [8]	F	D	NI	NI	YES	NI	NI
c.945-747 BC (XXI-XXIV dyn)	Cesarani 2004 [23]	M	D	NI	NI	YES	NI	NI
c. 800-700 BC (XXII dyn)	Seiler 2015 (D242) [22]	F	D	14, 15, 31, 32, 42, 44, 45	11, 21, 22	YES	NI	YES
c.746-525 BC (XXV-XXVI dyn)	Sigmund 2002 [24]	F	D	NO	NO	YES	24, 25	NI
c.600 BC (XXVI dyn)	Thekkaniyil 2000 [25]	M	D	46	NO	NI	NI	NI
Ptolemaic period	Singarella 1986 [9]	F	D	NI	NI	YES	NI	YES
Ptolemaic period (323-30 BC)	Babin 1990 (Se-Anht) [10]	F	D	YES	NO	YES	YES	NO
Ptolemaic period c.305-150 BC	Babin 1990 (Iret-Irew) [10]	M	D	YES	NO	YES	YES, multiple	YES, multiple
Ptolemaic period	Chan 2008 [26]	F	D	28, 37, 38, 47	NO	NO	NO	NO
Ptolemaic period	Gerloni 2009 (M3) [20]	M	D	All missing except 46	NO	NI	NO	YES, 46
Ptolemaic period	Pelo 2012 [27]	F	D	NO	NO	YES	31, 41	NO
Ptolemaic period	Wade 2012 (RM2720) [15]	F	D	NO	NO	NO	NO	NO
Ptolemaic period (323-30	Davey, 2013 [28]	M	M	NI	NI	NI	NI	NI

BC)								
Ptolemaic period	Zesch 2016 [29]	M	L	NO	NO	NO	NO	NO
100 BC-100 AD	Nickol 1995 [30]	F	D	NO	12	YES	12	NO
Roman period (c.80-110 AD)	Macleod 2000 [31]	M	D	NO	NO	NO	NO	NO
Roman period (30 BC-395 AD	Piombino-Mascali 2016 [32]	M	D	18, 28, 41, 45, 46, 48, 36, 38	11, 12, 21, 22, 23	YES	11, 14, 16, 24, 25, 26	NO

NI: no information provided by the article

Table 10 presents the relationship between sex and the dental status of the mummies. There seems to not be any sex-based differences in missing teeth, periapical lesions, caries, or teeth wear. Only fractured teeth seem more common in female mummies.

Table 10. Relationship between sex and the dental status of the mummies.

	Missing teeth	**Fractured teeth**	**Wear**	**Periapical lesions**	**Caries**
Male/Female	7/5	1/4	9/9	4/6	3/4

Tooth displacements

Table 11 presents different types of tooth displacements inside and around the skull and face. A displacement is defined as a tooth present outside the maxilla and/or the mandible. Teeth were displaced in 5 cases, they were not displaced in 15 cases, and no information was provided in 11 cases. Teeth were found to be displaced in the oral and neck area in 5 cases (from the XVIII Dynasty), in the skull in 1 case [22], and in another area (larynx) in 1 case. There seems to not to be a relationship between sex and the displacement of teeth outside of the maxillae.

Table 11. Anatomical regions of tooth displacements.

Historical period	**Study**	**Sex M/F**	**Displaced in oral/neck areas**	**Displaced in skull**	**Displaced in other areas**
2040-1674 BC (Middle Kingdom)	Yardley 1997 (ROM I) [11]	M	NI	NI	NI
2040-1674 BC (Middle Kingdom)	Yardley 1997, ROM II [11]	M	NI	NI	NI
2000 BC (Middle	Gupta 2008 [12]	M	NO	NO	NO

Kingdom)					
XVII Dynasty	Manley 2002 [13]	F	NI	NI	NI
XVII Dynasty	Marquez 2015 (VL1248) [14]	NI	NO	NO	NO
XVII Dynasty	Marquez 2015 (VL1232) [14]	NI	NI	NI	NI
XVIII Dynasty	Wade 2012 (RM2717) [15]	F	41, 46	NO	NO
XVIII Dynasty (1479-1424 BC)	Bianucci 2016 [16]	M	NO	NO	NO
XX-XXII Dynasty (1150-795 BC)	Lindsay 2015 [17]	F	YES (fragments in oropha-rynx)	NO	NO
XXI Dynasty (1085-950 BC)	Brier 2015 (male) [18]	M	NO	NO	NO
XXI Dynasty (1070-945)	Hill 1993 [19]	F	NI	NI	NI
XXI Dynasty	Gerloni 2009 (M2) [20]	M	NO	NO	NO
1000 BC	Wanek 2011 [21]	NI	NI	NI	NI
1000-800 BC	Seiler 2015 (0492) [22]	M	41, 31, 35, one molar	NI	NI
XXII Dynasty (945-715 BC)	Harwood-Nash, 1979 [3]	F	NI	NI	NI
XXII Dynasty (900 BC)	Melcher 1997 [6]	F	NO	NO	NO
XXII Dyn-asty (945-715 BC)	Baldock 1994 [7]	F	NI	NI	NI
XXII Dynasty (770 BC)	Hughes 2005 [8]	F	NI	NI	NI
XXII-XXIII Dynasty (945-715	Cesarani 2004 [23]	M	NI	NI	NI

BC)					
800-700 BC	Seiler 2015 (D242) [22]	F	YES (multiple)	YES (2 teeth)	YES (larynx)
XXV-XXVI Dynasty (700-650 BC)	Sigmund 2002 [24]	F	NO	NO	NO
500 BC	Thekkaniyil 2000 [25]	M	NO	NO	NO
334-304 BC	Singarella 1986 [9]	F	NI	NI	NI
Ptolemaic period (323-30 BC)	Babin 1990 (Se-Anht) [10]	F	NI	NI	NI
Ptolemaic period (323-30 BC)	Babin 1990 (Irt-Irw) [10]	M	NI	NI	NI
305-200 BC	Chan 2008 [26]	F	NO	NO	NO
Greek-Roman period	Gerloni 2009 (M3) [20]	M	4 teeth in oropharynx	NO	NO
200 BC	Pelo 2012 [27]	F	NO	NO	NO
Ptolemaic or Roman period	Wade 2012 (RM2720) [15]	F	NO (32 twisted at 90° and displaced lingually behind 31 and 33)	NO	NO
Ptolemaic period (323-30 BC)	Davey 2013 [28]	M	NI	NI	NI
378-235 BC	Zesch 2016 [29]	M	NO	NO	NO
100 BC-100 AD	Nickol 1995 [30]	F	NO	NO	NO
80-110 AD	Macleod 2000 [31]	M	NO	NO	NO
30 BC-395 AD	Piombino-Mascali 2016 [32]	M	NO	NO	NO

476 NI: no information in article
477
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Packing of the mouth, ears, nose, and eyes

Table 12 provides information about packing inside the mouth, ears, nose, and eyes. An open mouth was present in 13 cases (from the XVIII Dynasty). The mouth was closed in 9 cases (all historical periods), and no information was given for 9 cases. Packing of the mouth was present in 7 cases (from the XVIII Dynasty), no packing of the mouth was observed in 9 cases (from the XVIII Dynasty), and no information was provided in 15 cases (all historical periods). In 2 cases from the Roman period, a coin was placed inside the mouth. An open mouth with no packing was present in 4 cases (from the XVIII Dynasty). An open mouth together with packing was present in 4 cases (from the XVIII Dynasty). A closed mouth without packing was present in 3 cases (from the XXI Dynasty). A closed mouth with packing and a coin in the mouth was present in 1 case (Roman period). Packing in the mouth consisted of resin, resin soaked linen, mud, natron or myrrh. There were also bandages or plugs placed between the anterior teeth in 2 cases.

Table 12. Packing of the mouth, ears, and orbits.

Historical period	Study	Sex M/F	Mouth opened	Packing of the mouth	External Ear	Middle Ear	Foreign objects in orbit
2040-1674 BC (Middle Kingdom)	Yardley 1997 ROM I [11]	M	NI	NI	NI	Displace-ment of ossicular chain	NI
2040-1674 BC (Middle Kingdom)	Yardley 1997 ROM II [11]	M	NO	NI	Embalming material	absence of ossicular chain	NI
2000 BC (Middle Kingdom)	Gupta 2008 [12]	M	NO	NI	NI	NI	NO
c.1570-1520 BC (XVII dyn)	Manley 2002 [13]	F	NI	NI	Gold ear-rings	NI	NI
c.1570-1520 BC (XVII dyn)	Marquez 2015 (VL1248) [14]	NI	NI	NI	NI	NI	NI
c.1570-1520 BC (XVII dyn)	Marquez 2015 (VL1232) [14]	NI	NI	NI	NI	NI	NI
c.1479-1424 BC (XVIII dyn)	Wade 2012 (RM2717) [15]	F	NI	YES (natron or myrrh)	NI	NI	NO
c.1479-1424 BC (XVIII dyn)	Bianucci 2016 [16]	M	YES	NO	NI	NI	NI

c.1150-795 BC (End New Empire-3rd intermediary period)	Lindsay 2015 [17]	F	YES	NO (resin in pharynx)	NI	NI	NO
c.1069-945 BC (XXI dyn)	Brier 2015 [18]	M	YES	NI	NI	NI	NI
c.1069-747 BC (XXI –XXII dyn)	Hill 1993 [19]	F	YES	NI	NI	NI	NI
c.1069-747 BC (XXI-XXII dyn)	Gerloni 2009 (M2) [20]	M	YES	YES (bandages between anterior teeth)	NI	NI	YES, (false eyes : 2 oval radiopaque plates)
c. 1000 BC (XXI dyn)	Wanek 2011 [21]	NI	NO	NO	NI	NI	NO
c. 1000-800 BC (XXI – XXII dyn)	Seiler 2015 (0492) [22]	M	NI	NO	NI	NI	NI
c.945-747 BC (XXII dyn)	Harwood-Nash, 1979 [3]	F	NI	NI	NI	NI	False eye (left), eye globes packed
c.900 BC (XXII dyn)	Melcher 1997 [6]	F	YES	NO	NI	NI	NI
c.945-747 BC (XXII dyn)	Baldock 1994 [7]	F	YES	NI	NI	NI	False eyes (glass)
c.770 BC (XXII dyn)	Hughes 2005 [8]	F	YES	YES (plug between front teeth)	NI	NI	YES (false eyes: 2 plates)
c.945-747 BC (XXI-XXIV dyn)	Cesarani 2004 [23]	M	NO	NI	NI	NI	NI
c. 800-700 BC (XXII dyn)	Seiler 2016 (D242) [22]	F	NO	NI	NI	NI	NO
c.746-525 BC (XXV-XXVI dyn)	Sigmund 2002 [24]	F	NO	NI	NI	Intact internal ear structure	Packing (Eye bulbs filled with substance-600 HU)

c.600 BC (XXVI dyn)	Thekkaniyil 2000 [25]	M	YES	NO	NI	NI	False eyes: plates (2?)
Ptolemaic period	Singarella 1986 [9]	F	NI	NI	NI	NI	NI
Ptolemaic period (323-30 BC)	Babin 1990 (Se-Anht) [10]	F	NI	NI	Embalming material	NI	Linen strips (in front of the globes)
Ptolemaic period c.305-150 BC	Babin 1990 (Irt-Irw) [10]	M	NI	NI	NO	NI	Linen strips (in front of the globe)
Ptolemaic period	Chan 2008 [26]	F	NI	YES (resin)	NI	NI	NI
Ptolemaic period	Gerloni 2009 (M3) [20]	M	YES	NI	NI	NI	NI
Ptolemaic period	Pelo 2012 [27]	F	YES	NI	NI	NI	NI
Ptolemaic period	Wade 2012 (RM2720) [15]	F	YES	YES, resin-soaked linen, posteriorly mud?	NI	NI	NO
Ptolemaic period (323-30 BC)	Davey, 2013 [28]	M	NO	NO	NI	Intact ossicles in middle ears	False eyes
Ptolemaic period	Zesch 2016 [29]	M	NO	NO	Embalming material in external auditory canal (2079 HU)	NI	NO
100 BC-100 AD	Nickol 1995 [30]	F	YES	YES + metallic coin-like object	NI	NI	Linen
Roman period (c.80-110 AD)	MacLeod 2000 [31]	M	NO	Metallic oval plate over tongue	NI	NI	NI
Roman period (30 BC-395 AD	Piombino-Mascali 2016 [32]	M	YES	NO	NI	NI	packing

NI: no information in the article

Embalming material was found in the outer ear in 3 cases (from the Middle Kingdom), there was no embalming material in one case, earrings were present in one case, and no information about the outer ear was given in 26 cases. Middle ear content was described in 4 cases with intact ossicles (2 cases), displaced ossicles (1 case), and absent ossicles (1 case). Displaced and absent ossicles were found in mummies from the Middle Kingdom. Intact ossicles were found in this study in mummies from the XXV Dynasty and the Ptolemaic period.

Foreign objects in the orbits were found in 10 cases (from the XXI Dynasty). There were no objects in the eyes in 7 cases, and no information was provided about foreign objects in the eyes in 14 cases. False eyes were found in 4 cases (from the XXI Dynasty), eye packing in 2 cases (from the XXII Dynasty), false eye and packing in one case, and linen in 3 cases (from the Ptolemaic period).

Table 13 provides with information about the relationship between mouth opening, packing, and sex. It seems that mouth opening may be more common among females, however, this study sample is too small to provide any strong evidence.

Table 13. Relationship between mouth opening, packing, and sex.

Male/Female	Open (YES)	Closed (NO)
Packed (YES)	1/3	1/0
Not packed (NO)	3/2	2/0

Outer facial appearance

Table 14 provides information about the outer facial appearance. There were 12 cases of mummies with additional elements present outside of the face. There was no information for 18 mummies, and there was one case with no additional element on the face.

Nasal plugs were present in 5 cases (from the Middle Kingdom) with a ratio of 4 males to 1 female. Facial masks were present in 3 cases (from the Ptolemaic period). A rosette applique placed on the temple was present on a female mummy from the Ptolemaic period. There were also two cases of the presence of metallic elements in wrappings around the head and one case of an undermined type of foreign object close to the nostrils.

Table 14. Outer facial appearance.

Historical period	Study	Sex M/F	Supplementary outer appearance	Hair/other
2040-1674 BC (Middle Kingdom)	Yardley 1997 ROM I [11]	M	Nasal plug, right	NI
2040-1674 BC (Middle Kingdom)	Yardley 1997 ROM II [11]	M	Nasal plug, right	NI
2000 BC (Middle Kingdom)	Gupta 2008 [12]	M	Element inferior to right anterior nasal opening, on skin, in	Eyebrows drown on linen

			linen	
c.1570-1520 BC (XVII dyn)	Manley 2002 [13]	F	NI	NI
c.1570-1520 BC (XVII dyn)	Marquez 2015 (VL1248) [14]	NI	NI	NI
c.1570-1520 BC (XVII dyn)	Marquez 2015 (VL1232) [14]	NI	NI	NI
c.1479-1424 BC (XVIII dyn)	Wade 2012 (RM2717) [15]	F	Metallic element	Short, straight white hair
c.1479-1424 BC (XVIII dyn)	Bianucci 2016 [16]	M	NI	NI
c.1150-795 BC (End New Empire-3rd intermediary period)	Lindsay 2015 [17]	F	NO	NI
c.1069-945 BC (XXI dyn)	Brier 2015 [18]	M	NI	NI
c.1069-747 BC (XXI –XXII dyn)	Hill 1993 [19]	F	NI	NI
c.1069-747 BC (XXI-XXII dyn)	Gerloni 2009 (M2) [20]	M	NI	NI
c. 1000 BC (XXI dyn)	Wanek 2011 [21]	NI	NI	NI
c. 1000-800 BC (XXI – XXII dyn)	Seiler 2015 (0492) [22]	M	NI	NI
c.945-747 BC (XXII dyn)	Harwood-Nash, 1979 [3]	F	NI	NI
c.900 BC (XXII dyn)	Melcher 1997 [6]	F	NI	NI
c.945-747 BC (XXII dyn)	Baldock 1994 [7]	F	NI	NI
c.770 BC	Hughes	F	NI	NI

(XXII dyn)	2005 [8]			
c.945-747 BC (XXI-XXIV dyn)	Cesarani 2004 [23]	M	NI	NI
c. 800-700 BC (XXII dyn)	Seiler 2015 (D242) [22]	F	NI	NI
c.746-525 BC (XXV-XXVI dyn)	Sigmund 2002 [24]	F	NI	Present
c.600 BC (XXVI dyn)	Thekkaniyil 2000 [25]	M	NI	NI
Ptolemaic period	Singarella 1986 [9]	F	Rosette (on the left temple)	Short, razor-cropped brown hair
Ptolemaic period (323-30 BC)	Babin 1990 (Se-Anht) [10]	F	Rosette applique (on the right temple)	Close-cropped
Ptolemaic period c.305-150 BC	Babin 1990 (Irt-Irw) [10]	M	Nasal plugs (1 right side, 2 left side)	NI
Ptolemaic period	Chan 2008 [26]	F	Nasal plugs	NI
Ptolemaic period	Gerloni 2009 (M3) [20]	M	NI	NI
Ptolemaic period	Pelo 2012 [27]	F	NI	NI
Ptolemaic period	Wade 2012 (RM2720) [15]	F	Facial mask (gilded) over the face, Wadjet eye on the forehead of the mask	Tutulus (chignon) at the vertex of the head
Ptolemaic period (323-30 BC)	Davey, 2013 [28]	M	Facial mask	NI
Ptolemaic period	Zesch 2016 [29]	M	Facial mask (hyperdense) between the face and outer bandage	NI
100 BC-100 AD	Nickol 1995 [30]	F	NI	NI
Roman period (c.80-110 AD)	MacLeod 2000 [31]	M	Metallic elements in wrappings around head, portrait panel	NI
Roman period (30 BC-395 AD	Piombino-Mascali 2016 [32]	M	Nasal plug (right), Resin soaked linen over the face	NI

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The presence and the type of hair dressing was described in only 4 cases (only in female mummies), false eyebrows were painted on linen in one case, and no information was provided in 26 other cases.
Table 15 provides three different combinations of the presence of ethmoid fracture together with nasal plugs. The mummies from the Middle Kingdom presented with bilateral ethmoid fracture and a nasal plug on the right side [11]. The mummies from the Ptolemaic period presented with the following combinations: 1) bilateral ethmoid fracture and bilateral plug [10], and 2) right ethmoid fracture and nasal plug on the right side [26].

Table 15. Nasal plugs and excerebration pathways.

Historical period	Study	Sex M/F	Nasal plug	Nasal bone fracture	Ethmoid bone fracture	Sphenoid bone fracture
2040-1674 BC (Middle Kingdom)	Yardley 1997 ROM I [11]	M	Nasal plug, right	YES	YES, bilateral	NO
2040-1674 BC (Middle Kingdom)	Yardley 1997 ROM II [11]	M	Nasal plug, right	YES	YES, bilateral	NO
Ptolemaic period c.305-150 BC	Babin 1990 (Irt-Irw) [10]	M	Nasal plugs (1 on right side, 2 on left side)	YES, septum deviated to left	YES, bilateral	NI
Ptolemaic period	Chan 2008 [26]	F	Nasal plugs, right	NI	YES, right	YES, right
Roman period (30 BC-395 AD	Piombino-Mascali 2016 [32]	M	Nasal plug, right	YES, right	NI	NO

Duplicate studies

Among three duplicated cases (Djedmaatesankh, Tjentmutengebtiu, and Se-Ankh), there existed multiple discordances between the descriptions of the same mummy by different teams. First, there were differences in deciphering the name of the mummy itself and its titles, along with different approximations of the mummy's age (Table 1). The professional backgrounds and team compositions were different, which may explain the differences in analysis and in description of the mummies (Table 2). Studies were performed with different types of CT scans and using different radiological protocols which may have led to different conclusions (Table 3). The descriptive analysis of the mummy was often incomplete, and further studies have not added any new information on the same mummy (Tables 4, 6). Teeth visualization was also performed with different types of CT modalities which may have influenced the description and analysis of the dental status (Tables 8, 9, 11).

There were contradictory findings about the presence or absence of eye globes and eye muscles in the Tjentmutengebtiu mummy (Table 7), caries in the Se-Ankh mummy (Table 9), and the positioning of the rosette applique on the right/left side of the temple of the Se-Ankh mummy (Table 14).

Quality of the articles included in the systematic review

The evidence-based quality of the selected articles was low because the selected articles were only case reports and small case series. The EMBASE database did not add any article to our analysis.

Discussion

Computed tomography applied to Egyptian mummy heads has been used for almost forty years [3]. However, there exists a great diversity of radiological protocol modalities, types of image treatment procedures, and anatomical descriptions related to the quality of the provided images. Moreover, there exists no consensus among specialists regarding a standard CT description of an Egyptian mummy head and face [4]. This lack of a consensus explains why complete information on the diverse elements that should represent a full mummy description is not provided [33]. Therefore, only the application of a systematic categorization of data can provide us with new information on embalming techniques.

General information on selected cases

Regarding the study summarized in Table 1, there was an over-representation of mummies belonging to the XXI-XXII Dynasties and Ptolemaic period, which is in accordance with a systematic review by Zweifel et al. [2]. Additionally, the proportion of mummies with an estimated age to those with an unknown age in our study (2/3 to 1/3) was the same as in the Zweifel study [2]. There was an over-representation of author affiliations and museum collections from Anglo-Saxon countries, which was also reported by Zweifel et al. [2].

Author affiliations

One may think that when the main purpose of the study is related to CT imaging, Egyptology and head and face anatomy and related disorders, the authors should represent these three domains of expertise. However, the presence of a multidisciplinary team formed by a radiologist, an Egyptologist, and a maxillofacial surgeon (dentist) occurred in only 10% of the articles. Moreover, the 35% of the articles lacked the expertise of a radiologist, and 40% lacked the expertise of an Egyptologist. The fact that 41% of affiliations were outside radiology, Egyptology, dentistry, or even anthropology may render questionable the scientific quality of

such articles. There were also only 3 articles with an author with an ear-nose-throat affiliation, and this fact is reported in Table 12, with 24/31 cases missing information about ear embalming.

Computed tomography radiological protocol

Multiple devices and radiological protocols have been developed and used to scan Egyptian mummies since 1979 [3]. Therefore, a direct comparison between studies is not possible. However, the majority of cases present with a low-quality score between 0 and 3. Moreover, 6 studies had a score of 0, meaning that no radiological CT protocol was described in the article even if CT images of the mummy were presented and commented on. It is an example of a more general problem with peer-reviews of this type of interdisciplinary article. One of the main advantages of CT scanning is the Hounsfield unit scale, which allows one to compare and quantify different structures with close density. Hounsfield units were not used at all except in 2 cases to recognize an embalming substance in the middle ear [29] and a packing substance in the eye globe [24] (Table 12).

Excerebration pathways

Trans-nasal and trans-ethmoidal excerebrations were more frequent on the left side than on the right side, which is in accordance with the previous literature [34, 35]. This review showed that there exist various excerebration pathways, and brain embalming treatments in mummies that do not belong to the pharaoh's family or to the closely related aristocracy. This finding is in accord with the Wade et al.; review [36] and in contrary to the hypothesis that experimentation with excerebration was restricted to the king and queen's family, as stated by Herodotus and explained in Saleem's study [34]. The evolution of the excerebration pathway from trans-ethmoidal to trans-sphenoidal was proposed by Fanous et al. [35], and it is in accordance with our findings. We also hypothesize that the alternative excerebration pathways reported in some cases in this review were deliberate and did not result from accidental perforations during the passage of the instrument through the left nostril. For example, the passage through the nostril, ethmoid and the thin walls of the orbit, which are the medial wall, and the roof of the orbit, were performed precisely behind the frontal process of the maxillary bone, which is a thick bone, on the same side. The experimentation with this type of road may be performed first on dry skulls. The choice of excerebration pathway may be related to technical problems encountered by the embalmers [34] or to anatomical variations of the anterior cranial fossa, such as thickening of the cribriform plate, or enlargement of the base of the crista galli process, or pneumatisation of the orbital roof, and the crista galli. We also found that, contradictory to the findings of Saleem et al. [34], linen was placed inside the skull without any additional entrance other than the nostrils such as the parietal bone holes in the skull of King Merenptah, to help with the

procedure [34]. Saleem also reported but did not explain the presence of a resin-like substance on the walls of ethmoid cells in the skull of queen Tiye [34]. We found this type of resin present in the sinuses of the face in 2 cases belonging to the Ptolemaic period.

The presence of two layers of resin in the parietal and occipital area results from the manipulation of the head during the introduction of the resin to the skull. This technique was described as being used for Tutankhamun's skull [34]. We found 2 similar cases in a non-royal family from the XXI and XXII Dynasties.

Soft tissue preservation of facial tissues

The presence and persistence of intraorbital soft tissue structures in an Egyptian mummy was already reported by Sandison in 1957 using rehydration and histological methods [37]. However, the skull and face soft tissue description based on CT scanning has suffered from poor reporting by the authors. Diverse combinations have been described regarding the presence and the absence of the brain, the dura mater, and the dura cervical. They may be related to the technique, to the historical period, to substances used and to the time spent inside the skull removing the brain (by instruments and/or liquid substance dissolving the brain and/or the dura).

Dental status of the mummies

We found 3 cases described with full dentition, with no wear, and with no dental pathology among the 31 cases, and 28 cases with dental problems (90.32% of cases had dental problems), which contrasts sharply with Zweifel's findings (18%) [2]. This difference in findings can be explained by differences in the methodology used, such as the exclusion and inclusion criteria, the MeSH terms used, the differences in search equations, the different dental disease items checked, and our small sample of mummies compared with Zweifel's sample [2]. The best option for teeth visualization and for the description of dental disorders seems to be a CT pseudo-panoramic multiplanar reconstruction showing all dental arches. However, in clinical application this type of reconstructed image cannot be used for the diagnosis of caries, as the gold standard is intraoral apical radiography. Only major crown defects can be evaluated. Therefore, caries may be underestimated when only CT scans are used to evaluate the mummy's dental health. Fractured teeth appeared only on the maxilla in the incisor area. This fact might be correlated with modern hypotheses [22] about the significance of the opening of the mouth ceremony, which appears to not only be an abstract religious act. Periapical lesions (cysts, granuloma, osteitis) and caries were present in mummies from the XVIII Dynasty. However, as the sample of mummies was small, we cannot conclude that a major modification in diet occurred during the XVIII Dynasty. Displacement of the teeth inside and outside the mouth is not exceptional and seems to be a deliberate method used by the embalmers, as the body should contain all its organs when it is reborn.

Packing inside the mouth, ears, nose, eyes, and the outer appearance of the head and face

Different combinations were described concerning the mouth opening or closing together with its packing. These combinations may also be related to more practical aspects of the ceremony of the opening of the mouth [22]. Ear embalming is almost unknown and has been omitted from the articles dealing with descriptions of Egyptian mummy heads using CT imaging. It is also related to the fact that ear-nose-throat specialists are rarely invited to provide their expertise in this field of research. Eye packing and foreign objects in the eye are described in mummies from the XXI-XXII Dynasty [38]. However, there was no information about eye replacement in 45% of the articles describing mummy heads using CT imaging. Saleem et al., [34] provided some information about variations in nasal embalming. We propose that the variability of nasal embalming is linked with the excerebration pathway. Combinations may vary depending on the historical period. However, a much larger sample is needed to validate this approach. The shape and type of hair, which is available from 3D CT skull reconstructions, was also underestimated by the majority of authors as added-value information.

Limitations of the study

The main limitation of our study is the use of medical databases to research articles for an interdisciplinary review. We may have failed to find useful information in journals focused on archaeology and Egyptology that are not listed in the PubMed or EMBASE databases, even if CT scanning is strongly related to the medical field. We also found only 31 eligible cases, and a more definitive conclusion on the historical period of time connected to the appearance of any new method in the embalming process cannot be drawn. The limited number of included studies did not allow us to draw a more definitive conclusion on the relationships between sex and the different elements of descriptive analysis provided in this article. We were also not able to check the chronological age and the sex of each mummy and we only used the description provided in the selected articles. Moreover, because of the small sample of selected mummies, we were not able to link our findings with historical events in the history of Egyptian civilization, such as proofs of modification of diet by the appearance of more caries and periapical lesions, related to a specific period in history.

Conclusions

Finally, there is a need for more systematization of the radiological protocol and the description of Egyptian mummy heads. The tables we presented along with this study may serve as a possible example or template to provide a detailed description of a given individual and of the embalming technique used in a specific region of the

730 body. Moreover, open access to the CT images of mummies should be granted at
731 least for researchers to be able to obtain complete information missing from
732 manuscripts such as the IMPACT project about radiological mummy database
733 (http://impactdb.uwo.ca/IMPACTdb/Index.html) [39]. A multidisciplinary team is
734 mandatory to provide as much verified and as detailed information as possible for
735 any given mummified person.
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744 **Authors contribution:**

Author	Contributor role
Olszewski R	Conceptualisation, Data curation, Investigation, Methodology, Resources, Validation, Writing original draft preparation, Supervision, Writing review and editing
Hastir JP	Validation, Writing review and editing
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Danse E	Writing review and editing

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