Radiology

ORIGINAL RESEARCH ■ SPECIAL REPORT

Nondestructive Insights into Composition of the Sculpture of Egyptian Queen Nefertiti with CT[1]

Alexander Huppertz, MD
Dietrich Wildung, PhD
Barry J. Kemp, MA
Tanja Nentwig
Patrick Asbach, MD
Franz Maximilian Rasche, MD
Bernd Hamm, MD

Purpose: To assess the conservation status of, to gain information on the creation of, and to provide surface reformations of the core and the surface of the bust of the pharaoh-queen Nefertiti, considered to be one of the greatest treasures of ancient Egyptian art, with computed tomography (CT).

Materials and Methods: Multisection CT was performed with 0.6-mm section thickness. Two- and three-dimensional reformations were made to depict the core and the surface separately.

Results: The stucco layer on the face and the ears was very thin, a maximum of 1–2 mm thick. The rear part of the reconstructed crown showed two thick stucco layers of different attenuation values, indicating that a multistep process was used to create the sculpture. Within the stucco, a great number of air-equivalent hypoattenuating areas, filamentous fissures parallel to the surface, and an inhomogeneous bonding between the layers were delineated. Nefertiti's inner face was not anonymous, but rather delicately sculpted by the royal sculptor Thutmose. The comparison to the outer face revealed differences, including the angles of the eyelids, creases around the corners of the mouth on the limestone surface, and a slight bump on the ridge of the nose. According to the beauty ideals of the Amarna period, the differences had positive and negative effects and can be read as signs of individualization of the sculpture. The potential material-related weaknesses of the sculpture that were revealed at imaging necessitate careful handling, with the avoidance of any focal pressure and shearing forces in the crown and the shoulders.

Conclusion: CT imaging revealed construction techniques in Nefertiti's bust that had implications for conservation, as well as for an understanding of the artistic methods used in the creation of this masterpiece of art of the 18th dynasty.

[1] From the Imaging Science Institute (A.H., T.N., B.H.) and Department of Radiology (P.A., B.H.), Charité-Universitätsmedizin Berlin, Robert-Koch-Platz 7, D-10115 Berlin, Germany; Egyptian Museum of Berlin, Berlin, Germany (D.W.); Department of Oriental Studies, University of Cambridge, Cambridge, England (B.J.K.); Siemens Healthcare, Berlin, Germany (T.N.); and Department of Internal Medicine, Division of Nephrology, University Hospital Ulm, Ulm, Germany (F.M.R.). Received July 5, 2008; revision requested August 1; final revision received October 8; accepted October 17; final version accepted October 26. **Address correspondence to** A.H. (e-mail: *Alexander.Huppertz@charite.de*).

Nefertiti (meaning "the beautiful one has come") was the Great Royal Wife of the Egyptian pharaoh Akhenaten (Amenhotep IV). She became world famous through her painted bust, actually exhibited in the Old Museum, Berlin, Germany (inventory no. 21300), and now planned to be moved to the New Museum, Berlin, Germany, in 2009. Nefertiti was considered to have been the most renowned Great Royal Wife of all 31 dynasties. The generally strong position of a woman in ancient Egypt increased under Akhenaten's reign. Nefertiti became, to a large extent, coregent of Egypt and, at the very least, was symbolically bestowed with the powers of a pharaoh. This was evident through various scenes where she was depicted in the position of pharaoh (ie, smiting the enemies). There was also speculation, owing to depictions in the rock tombs of Amarna, Egypt, that she may have had a dominant role in ruling along with Akhenaten under the name "Smenkhkare" in the later years of her husband's reign. One theory asserted, against all previous assumptions, that she may have survived Akhenaten's death and even reigned over Egypt alone for a short time afterwards. Nefertiti's death is still a mystery. The cause of death, as well as time and location, were unknown, as she vanished from historical record after a certain date. Theories dated her death to 1338 BC, the year 14 of her husband's reign. There were speculations of her being murdered or falling into disgrace. If she succeeded to the throne as Smenkhkare, she disappeared after a few years, together with her daughter and coruler Merytaten (1).

Nefertiti's bust was discovered on December 6, 1912, during excavations led by the Egyptologist Ludwig Borchardt (1863–1938) (Fig 1a) under the aegis of the German Oriental Society. These excavations were financed mainly by the Berlin, Germany, patron of the arts James Simon (1851–1932). The bust was excavated in the ruined studio complex of the royal sculptor Thutmose; this complex was labeled P 47.1–3 (2). Thutmose was considered to have been the most renowned artist in the city of Amarna, Egypt, under the aegis of Akhenaten. Thutmose's name was conveyed by an ivory blinder with the inscription "Thutmose, chief of the work," found in the ruins (1).

On the occasion of the partition of the finds between Egypt and the licensed excavator, the inspector of antiquities for the Egyptian government, Gustave Lefebvre (1879–1957), awarded the bust to the German expedition. With its height of 48 cm (18 7/8 inches), the bust fascinated the eye by its accomplished craftsmanship and gracefulness (Fig 1b).

Computed tomography (CT) is widely used for a variety of nonmedical purposes in view of its high spatial and attenuation resolution (3–5) and nondestructive nature. In 1992, Nefertiti's bust was examined for the first time by using CT. Wildung (5) and Zwicker et al (6) demonstrated that the bust had a core of limestone and that parts of the outer surface, especially the areas of the crown and shoulders, were covered with an extra layer of stucco. The discovery of the complex, multilayered construction of the bust was proof enough to vitiate theories that the bust was a fake and was constructed by modern manufacturing. A detailed analysis of the surface of the core was not possible at that time, as a section thickness of 5 mm was used at the CT examination (7).

A newer thin-section CT technique with submillimeter section thickness was performed to precisely assess the conservation status of the bust, to gain information on the creation of it, and to provide a three-dimensional surface reformation of the inner limestone sculpture. The reformation of the inner surface was compared with the visible outer surface and was explained in the historical context of the artwork. The findings were inspected to possibly differentiate multiple layers of plaster. The bonding between limestone and plaster was analyzed to identify points of weakness that are potentially at risk for breaking and to provide guidance for handling of the bust. In addition, the limestone core was analyzed for homogeneity and for inclusions that could provide information to help determine the origin of the stone.

Thus, the purpose of this study was to assess the conservation status of the bust of the pharaoh-queen Nefertiti, which is considered to be one of the greatest treasures of ancient Egyptian art, to gain information on the creation of the bust, and to provide surface reformations of the core and the surface of the bust with CT.

Advances in Knowledge

- By using CT, the hidden inner face of Nefertiti's painted bust was unmasked for the first time, without having to damage this rare art treasure.
- CT showed that the facial stucco layer was very thin and that only minor but nonetheless meaningful modifications were made by the royal sculptor Thutmose.
- CT provided data for a more comprehensive understanding of the creation of the bust and of the modification processes that were involved in the inner limestone core, particularly the adding of thick layers of stucco in the shoulders and in the rear area of the crown and the adding of a thin layer in the face.
- The details of the CT findings suggest the hypothesis that the thin facial layers may have been designed to individualize the portrait.
- In addition, CT findings indicating areas of material weakness may be used to prevent damage of this extremely precious art object.

Materials and Methods

Imaging

CT was performed with the bust in the supine position by using a medical mul-

Published online
10.1148/radiol.2511081175

Radiology 2009; 251:233–240

Abbreviation:
SD = standard deviation

tisection CT unit (Somatom Sensation 64; Siemens Healthcare, Berlin, Germany). The acquisition was performed with the spiral technique, with simultaneous acquisition of 64 sections with a section thickness of 0.6 mm (Table). Axial images of 0.75- and 2.5-mm section thickness were reconstructed. The bust was depicted at a workstation equipped with a three-dimensional–volume data-set display (Syngo InSpace 4D, version VB20; Siemens Healthcare), freely rotatable in all dimensions and viewing angles, by using a smooth-image reconstruction algorithm (kernel B20f). The thin-section images were analyzed in sagittal, coronal, and oblique reformations of 2-mm section thickness and were postprocessed with a real-time volume-rendering technique to differentiate materials with different attenuation values, such as limestone and stucco, and to depict the inner core of the bust separately.

Region-of-Interest Analysis

Region-of-interest analysis was performed by measuring the attenuation value, in Hounsfield units, of the different materials of the bust. The regions of interest were drawn as large as possible, avoiding areas visually classified as a material mix. Three regions of interest per material were drawn by one investigator (A.H.) who recorded means, standard deviations, and surfaces.

Results

Differentiation among Three Main Materials

Three materials with different attenuation values and no significant overlap in their respective Hounsfield units were detected. Examination of the core, known to be made of limestone (calcium carbonate) from the examination of the uncovered parts in the left side of the rear area of the crown and in the lateral area of the shoulders (8), revealed a mean range of attenuation values of 1308–1350 HU (standard deviation [SD], 41–67 HU); examination of the outside, known to be made of stucco (calcium hydroxide) (8), revealed a mean range of attenuation values of 576–925 HU (SD, 42–131 HU); and examination of the focal regions in the inner part of the limestone revealed a mean range of attenuation values of 1651–2089 HU (SD, 46–110 HU), probably corresponding to that of flint stone. A total bust volume of 11 689 cm^3, with a threshold level of attenuation set between 400 and 2500 HU, was calculated.

The highest percentage of volume (84.7%; volume, 9906 cm^3) had attenuation values between 1001 and 1600 HU, and these values corresponded to those for limestone. A volume of 1107 cm^3 revealed attenuation values between 400 and 1000 HU, which corresponded to values for stucco (9.5%); and the residual volume of 676 cm^3 (5.8%) revealed attenuation values between 1601 and 2500 HU, which corresponded to the values for the inclusions in the core and a small volume of crystal rock for the right eye.

The core revealed diffuse well-delineated band-shaped inclusions of a material with attenuation values of more than 1600 HU. These inclusions were located predominantly in the neck and the rear part of the head, mostly on the right side, with an orientation vertical to

Figure 1

a. b.

Figure 1: Discovery of Nefertiti's bust. **(a)** Draggled statue in hands of supervisor of excavation, Hermann Ranke (at left), and an assistant foreman in Amarna, Egypt, on December 6, 1912. (Reprinted, with permission, from State Museums of Berlin, Egyptian Museum and Papyrus Collection, Berlin, Germany, photo archives.) **(b)** Image of bust taken at the Old Museum, Berlin, Germany. In the exhibition, a carefully adjusted illumination technique is used to put facial features more in evidence. (Reprinted, with permission, from State Museums of Berlin, Egyptian Museum and Papyrus Collection, Berlin, Germany; inventory no. 21300; photograph taken by Jürgen Liepe.)

the base and parallel to the front view. Three wedge-shaped formations located at the left supraauricular level (mean range of attenuation values, 2065–2089 HU; SD, 46–99 HU), in the dorsal area (mean range of attenuation values, 1651–1821 HU; SD, 57–105 HU), and on the right side (mean range of attenuation values, 1980–2040 HU; SD, 84–110 HU) at the level of the ear were particularly conspicuous.

In preparation for the first public exposition of the bust in Berlin, Germany, two metallic pins were drilled in the base of the bust inside of the core (sometime before 1924) (8). The larger pin in central positioning had a length of 120 mm and a diameter of 13 mm (Fig 2a); a second pin in the right half of the bust had a length of 39 mm and a diameter of 7 mm.

Modeled Thick Layers of Stucco

Thick layers of stucco at the level of the shoulders (Fig 2b) and in the rear part of the crown were identified. The maximum thickness of the stucco layer was 25 mm in the rear area of the crown (Fig 2a). Two different stucco layers were distinguished by their attenuation values (Fig 2c): the inner layer, with a mean range of attenuation values of 576–641 HU (SD, 69–131 HU), and the outer layer, with a mean range of attenuation values of 822–888 HU (SD, 81–148 HU). The higher attenuation values of the outer layer correlated with a higher physical density, caused by a greater amount of the limestone additive. At the level of the shoulders (Fig 2b), no different layers could be delineated (mean range of attenuation values, 901–925 HU; SD, 42–51 HU). In both the shoulders and the layers of the crown, a great many inclusions, typical for a mixed material, with air-equivalent attenuation values as low as −536 HU could be delineated. These inclusions had a diameter of up to 5 mm (right shoulder, ventral area). In addition to the inclusions, filamentous fissures orthogonal and parallel to the surface could be delineated (Fig 2d).

With the exception of fissures in the region of the ventral left shoulder, in the lower surface of the frontal thorax, and in the left side of the crown, the connection between the limestone and the stucco (inner) layers appeared uninterrupted, and only small incidental inclusions but no cracks could be observed. The area in the left side of the rear area of the crown, however, appeared particularly fragile (Fig 2e). The fissure adjoined directly dorsally to a large defect in the stucco layer, which was visible externally and was approximately 99 × 60 mm. This was of historical origin, because it was previously described by Ludwig Borchardt in his discovery reports from 1923 (2,8).

In the two stucco layers in the crown, the connection between layers revealed discontinuities, with a higher number and larger size of inclusions, in comparison with the connection between the core and the inner layer. In particular, two locations, each with an extension of approximately 10 × 8 mm, thin hypoattenuating areas, as a sign of locally unbounded stucco layers, could be identified in the rear area of the crown (Fig 2c).

The location of a previously recognized defect in the ventral surface of the thorax was delineated (Fig 2d). The restoration performed between 1980 and 1984 (9) was done with a homogeneous material of higher attenuation values (mean range of attenuation values, 1050–1060 HU; SD, 66–77 HU) than that of the surrounding stucco. Many air-equivalent hypoattenuating areas in the area of contact could be recognized. This finding suggested that the defect was refilled with new material and that the original pieces of stucco were not reattached.

Right and Left Eyes

The right eye showed mean attenuation values between −430 and −496 HU (SD, 125–206 HU), corresponding to the attenuation of air (Fig 2f). The lens of the inlaid eye consisted of rock crystal (9), with a thickness of 2 mm and a mean range of attenuation values of 1610–1780 HU (SD, 160–296 HU). The pupil, made of black-colored wax, could not be delineated at CT. The eye sockets were roughly symmetric, with a depth of approximately 3 mm (Fig 2f). The left eye seemed to have never been filled with an inlay (10) and contained no lens and no pupil. Although this finding would be considered very unusual by today's standards, the bust was probably just a working model at the time of its creation, serving as a copy model. Thutmose demonstrated how to make the hollow in which the eye would finally be set in the carved stone.

Unmasking of a Second Hidden Face

A visual separation of the core's surface from the outer layer was performed (Fig 3a, 3b). The slightly bumpy surface was caused by the boundary artifacts between the layers (Fig 3b). In the face, the plaster layer was shown to have been extremely thin, with a maximum thickness of 1–2 mm (Figs 2a, 3c, 3d). The face of the core was very delicately carved, appeared highly symmetric, and could have certainly been a realistic portrait of the queen. It differed in some important details from that of the visible outer surface (Fig 3c). The corners of the eyelids showed less depth and appeared less three-dimensional. There were creases around the corners of the mouth and cheeks, a less harmonious nose ridge, and less prominent cheekbones. The nose showed a slight bump at the height of the chondral transition (Fig 3e, 3f). The area around the cheekbones of the inner face appeared less three-dimensional than they were in the outer face, where they were shaped more prominently. Both ears bared only distinct traces of being remodeled (Figs

Acquisition Parameters of CT

Parameter	Value
Section collimation*	64 × 0.6
Section width (mm)	0.6
Spatial resolution (mm)	0.4
Reconstruction increment (mm)	0.5
Rotation time (sec)	0.5
Pitch	0.8
Tube voltage (kV)	120
Effective tube current–time product (mAs)	400
Kernel	B20f

* Value for collimation refers to number of sections and section thickness in millimeters.

Figure 2

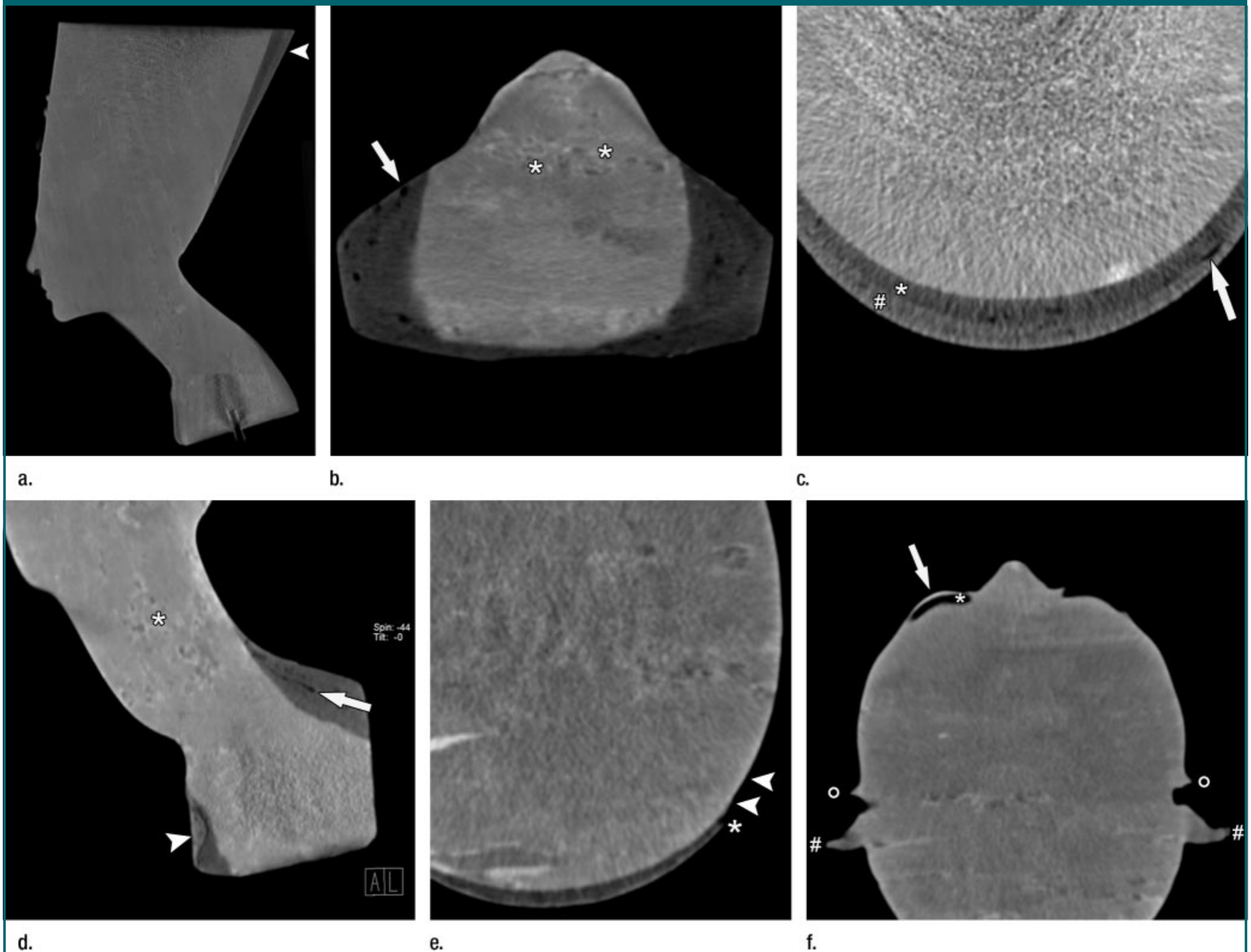


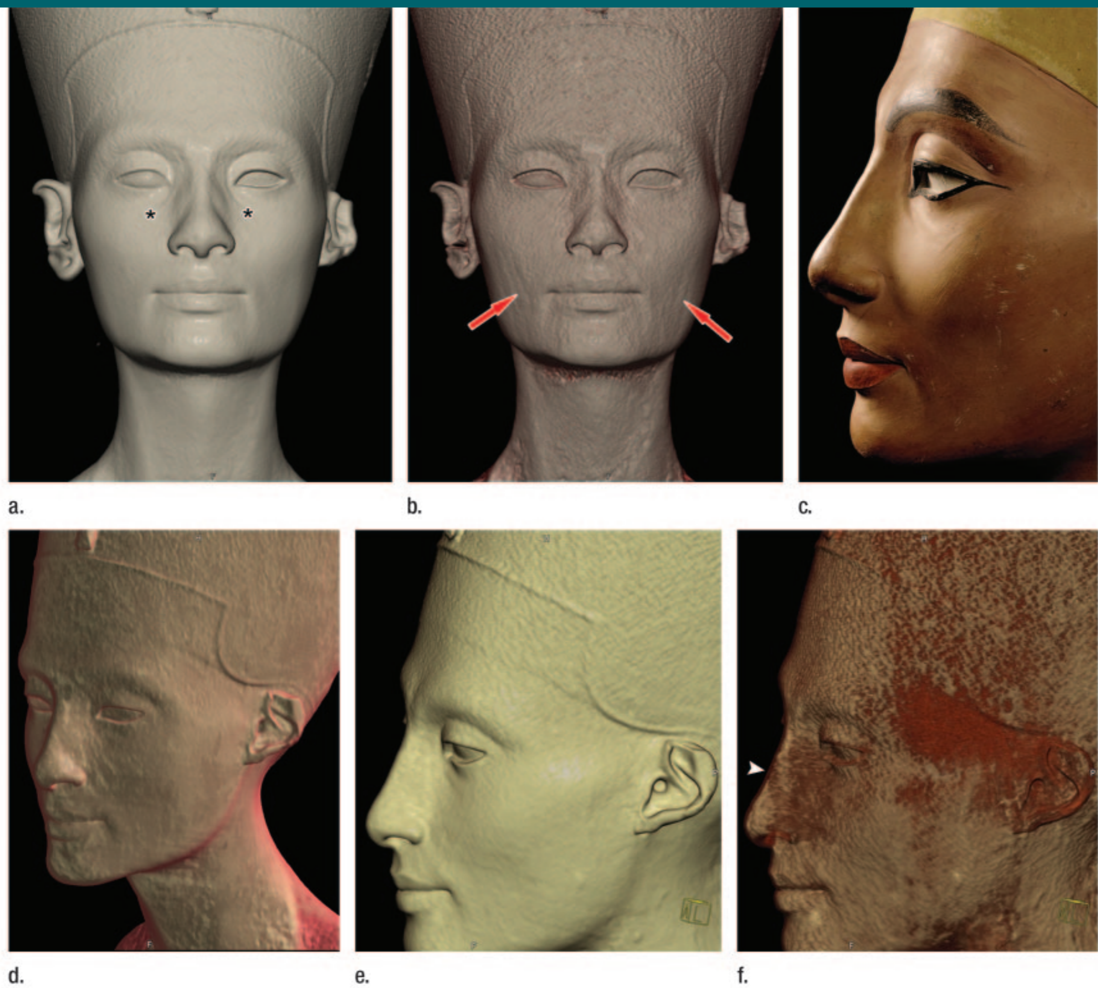
Figure 2: Two-dimensional **(a)** sagittal and **(d)** oblique (section thickness, 2 mm) and **(b–f)** axial (section thickness, 2.5 mm) reformations. **(a)** Layers of stucco in rear area of crown can be delineated (arrowhead). In contrast, face is covered with minimal layer of stucco and is chiseled nearly completely in stone. Metallic pin is observed in base of bust. **(b)** Section at level of shoulders. Laterally, thick layers of stucco can be delineated. In contrast, dorsal site of bust reveals thin layer of stucco. Hypoattenuating inclusions in stucco (arrow) and hyperattenuating inclusions (*) in core with attenuation of more than 1600 HU with orientation parallel to front view, probably corresponding to that of flint can be delineated. **(c)** Magnification of crown: Two different layers with differences in attenuation can be observed. Small inclusions are delineated in both stucco layers. In addition, linear inclusions can be delineated as a sign of local unbinding of stucco layers (arrow). Outer layer (#) has higher attenuation than inner layer (*). **(d)** Oblique view of defect in ventral surface of chest (arrowhead). Restoration was done with material of higher attenuation compared with that of surrounding stucco. Fissure parallel to dorsal surface in left shoulder (arrow) and hyperattenuating inclusions in neck (*) were observed. **(e)** Magnification at basal level of rear area of crown. Superficial damage was confirmed at CT as blistering of stucco (arrowheads); dorsally, 2-mm fissure extends below intact stucco (*). **(f)** Section at level of eye sockets and ears. Cavum of right eye (*) shows mean attenuation between −496 and −430 HU, corresponding to that of air. Surface of right eye (arrow) consists of 2-mm-thick rock crystals. Details of both ear auricles, helix (#), and tragus (○) are chiseled in limestone.

2f, 3g, 3h). They were based on the very detailed limestone composition. The ear canals could have been shaped with different tools. The asymmetry in the shape seemed acquired, owing to damage, and was more prominent in the left ear (Fig 3h). The right ear canal showed a pointed end, which suggested the use of a drill-type tool, whereas the left ear canal ended bluntly.

Discussion

The reign of Akhenaten and his wife Nefertiti was marked by important cultural and religious changes. For the first time in Egyptian history, a new monotheistic religion was introduced and the royal couple communicated more openly about their private life than their predecessors had. Approximately in the 5th year of their regency, the government and center of public life moved from Thebes to Achet-Aton, a com-

Figure 3



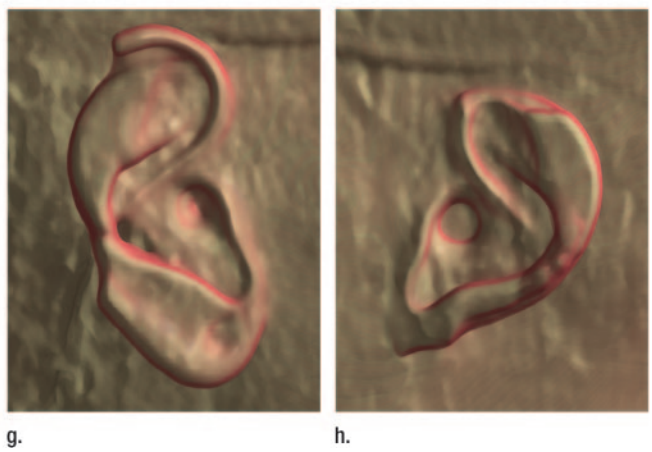


Figure 3: Three-dimensional volume-rendered reformations of **(a)** visible outer layer and **(b)** hidden inner layer. Threshold value for surface depiction was set to level higher than 900 HU to subtract outer stucco layer. **(a)** More pronounced shaping of eyelid corners (*) in comparison with inner layer can be seen. **(b)** Creases in corners of mouth (arrows) were detected. Note slightly bumpy surface caused by boundary artifacts between stucco layer and limestone core. **(c)** Photograph of lateral view of bust. (Reprinted, with permission, from State Museums of Berlin, Egyptian Museum and Papyrus Collection, Berlin, Germany; inventory no. 21300; photograph taken by Jürgen Liepe.) **(d)** Oblique surface rendering of face shows hidden inner core and added thin layer of stucco (depicted transparently in red). Detailed surface rendering of nose of **(e)** visible outer layer and **(f)** hidden inner layer. On **f,** outer layer is depicted with red and high level of transparency to facilitate comparison between surfaces of two faces. On **e** and **f**, slight bump at height of chondral transition not visible on **e** can be seen on limestone core on **f** (arrowhead). Detailed surface reformation of **(g)** right and **(h)** left ear conchae. Outer layer in red and high level of transparency is overlaying inner layer with sandy color. Both ears bear only thin layers of stucco. They are chiseled with high level of details in limestone. On **g**, right canal shows pointed end, whereas on **h**, left canal ends bluntly.

pletely new city, which is known today as Amarna, Egypt, that had been constructed in a relatively short time. Nefertiti's strong political influence is evident when one realizes that in no other period of Egypt's ancient history was the king always depicted in the company of his wife in representations of official ceremonies.

A more profound knowledge of the sculpturing of Nefertiti's bust can improve the understanding of this eventful period in Egyptian history. Of course, causing any damage to this precious art object would be unimaginable. Nondestructive thin-section multidetector CT impressively demonstrated that the inner core was not just an anonymous mold but, with the exception of the shoulders and the crown, rather a skillfully rendered work of quality art. This could be seen especially in the face and the ear auricles; their fine structure was already evident in the limestone bust and was only slightly modified with stucco. On both sides, the helixes, as well as the tragus, were artfully modeled in limestone. This finding suggested that physiognomic alterations achieved with stucco were done on purpose by the artist. In Thomas Mann's novel *Joseph and His Brothers* (11), the influence of the artistically depicted and the consignor of the depiction were described as "a mistake committed by the mind and not by the artist." In the chapter "The Child of the Cave" in the fourth volume of this novel titled *Joseph the Provider* (12), Joseph mentioned how Akhenaten ordered the sculptor to modify a model of princess Baketaton so that "she resembles the truth which is the light [the ancient Egyptian sun-god Aten] and the life led by the pharaoh." Although Thomas Mann, the 1929 Nobel Prize laureate in literature, was neither an Egyptologist nor a theologian, his highly precise religious and cultural studies represent an excellent reference for understanding the profound changes in the art and in the status of artists in Akhenaten's new monotheistic religion. It is possible that the bust of Nefertiti was commissioned (probably by Akhenaten himself) to represent Nefertiti according to his personal perception.

Considering the aesthetic ideals of the Amarna period (13), in which cosmetics were used to avoid or conceal wrinkles, the face of the bust was modified in both positive and negative ways. Retouching the creases in the corners of the mouth and equalizing the nose ridge could have been seen as embellishments, whereas the more pronounced shaping of the eyelid corners would have been considered unfavorable. The entirety of the changes allowed the conclusion that the bust had been individualized and personalized but not optimized. This interpretation is consistent with hypotheses of past years that, especially after optimizing the illumination on the sculpture, considered the outer surface of Nefertiti's bust not as that of a woman of flawless beauty but more an association with the image of a wise, mature woman with wrinkles underneath her eyes and drooping corners of her mouth (14,15). The wrinkles in the area of her cheeks could have also been seen on other depictions from her time period, as shown in figure 81 of the book by Arnold (16), and could therefore be realistic. Exceptionally during the Amarna period with its monotheistic religion, portraits of the pharaoh couple were intended to communicate cultural values and were less realistic than contemporary portraits. Nevertheless, various pictures were known that confirm the lineaments of the inner sculpture. In an unfinished representation of Nefertiti (Egyptian Museum, Berlin, Germany; inventory no. 21220) from the studio of Thutmose, she was seen with a rather flat and slightly bumpy nose ridge, as shown in figure 67 of the article by Priese (17).

In the inner of the bust's core, further artistic details were identified. The extensive areas with high attenuation values could have been derived from flint inclusions. In the form of nodules and layers, these occurred plentifully in limestone rock in certain districts of Egypt (18). The variation of the ear canals in the otherwise quite symmetric ears could have been explained by the flint inclusions situated predominantly in the right side of the back of the head. During Akhenaten's reign, tools were made mostly of solid stones or bronze and not of hardened iron, which was not known in that area. In contrast to the limestone that could be easily sculpted, no material harder than flint was known. The sculptors arduously tried, therefore, to work flint with specially shaped tools of the same material.

Some findings we noted at CT will be helpful in preventing damage to the bust. The double layers in the stucco of the rear part of the crown indicated a multistep manufacturing process. In addition, multiple air-equivalent hypoattenuating areas were covered in all regions with thick stucco layers (the rear area of the crown, the shoulders, and the thorax). These inclusions were found very close to the surface. Furthermore, different fissures parallel to the surface were found in the shoulders, the lower surface of the bust, and the rear part of the crown. For this reason, a very careful handling of the bust and the absolute avoidance of any focal pressure and shearing forces in the regions covered with thick stucco layers is imperative. The details of the multilayer stucco on the rear part of the crown with a higher attenuation of the outer layer and an inhomogeneous bonding between the two layers represent an additional material-related weakness of Nefertiti's bust.

In conclusion, although thin-section CT provided new information regarding the creation of Nefertiti's bust and unmasked, for the first time, the hidden inner face, it just as importantly provided documentation of the conservation status of the bust and precious information on how to avoid future damage to the art treasure. The CT examination findings support the interpretation that Nefertiti's bust is a masterpiece of the art of the 18th dynasty, which in its best creations constitutes an intersection between realism and stylization.

References

1. Reeves N. Nefertiti's disgrace. In: Akhenaten: Egypt's false prophet. London, England: Thames & Hudson, 2001; 169–173.
2. Borchardt L. The painted bust: portrait of Queen Nefertiti. In: Excavations of the German Oriental Society in Tell el-Amarna.

Leipzig, Germany: J. C. Hinrich Library, 1923; 30–38.

3. van Kaick G, Delorme S. Computed tomography in various fields outside medicine. Eur Radiol 2005;15(suppl 4):D74–D81.
4. Jansen RJ, Poulus M, Kottman J, de Groot T, Huisman DJ, Stoker J. CT: a new nondestructive method for visualizing and characterizing ancient Roman glass fragments in situ in blocks of soil. RadioGraphics 2006;26:1837–1844.
5. Wildung D. Insights: non-destructive examinations of ancient Egyptian objects. In: Annual Prussian cultural heritage. Vol XXIX. Berlin, Germany: Gebr Mann Library, 1992; 133–156.
6. Zwicker C, Hosten N, Wildung D, Felix R. Nefertiti: analysis of the bust with three-dimensional CT [in German]. Dt Aerzteblatt 1992;89:A2757–A2762.
7. Lemke AJ, Hosten N, Beier J, Wildung D, Zwicker C, Felix R. Non-destructive examination of Egyptian works of art [in German]. Med Bild 1995;2:55–62.
8. Anthes R. Queen Nefertiti's bust. Berlin, Germany: Gebrueder Mann, 1981; 5–11.
9. Krauss R, Wiedemann HG. The black in Nefertiti's eye. In: Annual Prussian cultural heritage. Vol XXXIV. Berlin, Germany: Gebr Mann Library, 1997; 211–222.
10. Arnold D. The workshop of the sculptor Thutmose. In: The royal women of Amarna. New York, NY: Abrams, 1996; 65–70.
11. Mann T. Joseph and his brothers [in German]. Frankfurt, Germany: Fischer Library, 2003.
12. Mann T. Joseph the provider. Vol IV. In: Mann T. Joseph and his brothers [in German]. Frankfurt, Germany: Fischer Library, 2003; 144–147.
13. Lembke K, Schmitz B, eds. Beauty in old Egypt: the search for perfection. Hildesheim, Germany: Gerstenberg, 2006.
14. Wildung D, Wullen M, Wenderholm I, eds. Hieroglyphics! the myth of pictographies from Nefertiti to Andy Warhol. Berlin, Germany: DuMont, 2005; 54–55.
15. Wildung D. Egyptian Museum and Papyrus Collection Berlin. Munich, Germany: Prestel, 2006; 74–75.
16. Arnold D. Aspects of the royal female image during the Amarna period. In: The royal women of Amarna. New York, NY: Abrams, 1996; 89–90.
17. Priese KH. Egyptian Museum. Mainz, Germany: Zabern, 1991; 110–111.
18. Lucas A, Harris JR. Stones, other than building stones and precious stones: stones vessels. In: Ancient Egyptian materials and industries. London, England: Ewald Arnold, 1962; 411–412.