Virtual autopsy investigation of gallstones in an 18th century Sicilian mummy

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Abstract. Gallstones represent a relatively rare finding in ancient human remains, and they are almost always related to high social classes. We report gallbladder stone disease detected by computed tomography-guided virtual autopsy in an 18th century natural mummy found in the Church of Sant'Anna in Modica, south-eastern Sicily. The mummified body was conservatively investigated by external examination and computed tomography (CT) scanning. 3D rendering and virtual autopsy approach enabled us to recognize multiple stones in the gallbladder, whereas densitometry allowed us to reconstruct the exact stone morphology and establish the chemical composition. The mummy belonged to an anonymous plump elder man with poor dental status, calcified lung nodules, pelvic phleboliths, and severe osteoarthritis of the spine and the right hip. Seven gallstones measuring 1.3 to 2.0 cm in largest diameter were observed. They had ellipsoid shape and inhomogeneous morphology with central hypodense cores and density values ranging from 70 to -289 Hounsfield Units (average: -40). These features suggested combined cholesterol gallstones. Gallstones may be easily recognized in natural mummies through a CT-guided virtopsy approach, whereas densitometry may help to establish their chemical composition. In the present case, cholesterol-based stones were probably due to dietary factors and genetic predisposition like their modern counterparts. Along with the other pathological findings (obesity, phleboliths, dental status) gallbladder stones represent a good bioanthropological marker of high social class.

Key words: gallstones, mummies, Sicily, paleopathology, paleoradiology

Introduction

Gallbladder stones represent a relatively rare finding in ancient human remains. As their modern counterparts, gallstones are almost always related to high social classes and well-nourished people (Glenn, 1971; Beal, 1984; Lammert, 2022). To the best of our knowledge, ancient cholelithiasis has been described in mummified or skeletal remains of 21 subjects from Egypt, Europe, and South America, dating back from the Second Millenium to the 16th century of the modern era. The age at death of the subjects was between 25 and 60 years old, with a female predominance, and a 3:1 ratio of cholesterol: pigmented stones (Weisberg, 1984; Steinbock, 1990; Ellis, 2019).

We present a case of gallbladder stone disease radiologically detected in an 18th century natural mummy found in the church of Sant'Anna, Modica, south-eastern Sicily (Ventura et al., 2024).

Material and methods

The mummified body of an anonymous individual was found during restoration works at the Sant'Anna church in Modica, Sicily. The mummy (identified as MSA2) underwent superficial cleaning and external inspection, digital radiology, and computed tomography (CT) scanning. A vestimentary analysis of the original garments was performed in order to date the body (Figure 1).

Direct radiograms of the body in different projections were obtained with the Philips Omni Diagnost digital radiology system. Subsequently, the mummy underwent CT scanning using a General Electric LightSpeed Pro 32 scanner with 0.625 mm thick sections, obtained with a 1:1 pitch at 50 mA and 120 kV, with maximum field of view (FOV) 47.1 x 47.1. Tomodensitometric measurements were made according to the Hounsfield scale (HU: Hounsfield unit). Volumetric 3D rendering was carried out to obtain reconstructions of external and internal aspects of the mummy. DICOM files obtained with CT scan were loaded in the Anatomage Table EDU^{TM}, version 10.1.1 to perform virtual dissection of both hard and soft tissues by multiple anatomical projections.

A fully digital bio-anthropologic survey by analysis of age-at-death, height, ergonomic indicators, and the study of occupational markers was carried out in order to reconstruct the lifestyle and physical traits of the subject (Buikstra & Ubelaker 1994; Capasso et al., 1999; Mariotti et al., 2004; Mariotti et al., 2007).

Figure 1. The mummy at the beginning of the scientific investigations.

Results

The natural mummy belonged to a plump elder man (more than 60 years old) who died in 1785-1795 A.D. He was 169 cm long and showed evidence of poor dental status, pulmonary tuberculosis, pelvic phleboliths, and severe osteoarthritis of the spine and the right hip. Full paleopathological details about this subject were reported in a previous publication (Ventura et al., 2024).

Digital radiograms showed the presence of multiple, weakly radiopaque stones in the right upper abdomen (Figure 2). Their presence was confirmed by multiplanar CT scans, which also allowed us to visualize the thin fibrous wall of the gallbladder (Figure 3). The total number of the gallstones was 7, and their larger diameter ranged from 1.3 cm to 2.0 cm. They had an ellipsoid shape and inhomogeneous morphologic pattern with central hypodense cores. Densitometry values of the stones ranged from 70 to -289 HU (average density: -40 HU) (Figure 4). Such features allowed us to recognize combined cholesterol gallstones.

3D reconstructions of the body followed by virtual dissection of the area enabled us to highlight the gallstones by isolating them from the surrounding structures (Figures 5 and 6).

Figure 2. Direct radiogram of the body in antero-posterior projection. Weakly radiopaque concretions in the right upper abdomen.

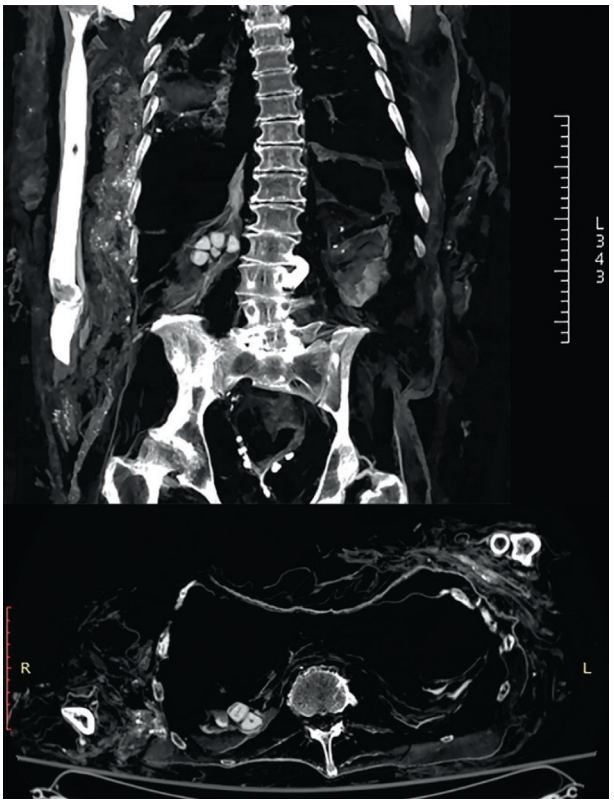

Figure 3. CT multiplanar reconstructions on coronal (above) and transverse plans (below). Hypo- isodense stones are surrounded by thin layers of soft tissue.

Discussion

Gallstones may be extremely well-preserved in natural mummies. To the best of our knowledge, 21 cases of cholelithiasis have been reported in paleopathological literature (Mörner, 1936; Gray, 1967; Wei, 1973; Munizaga et al., 1978; Sanchez et al., 1991; Cesarani et al., 2009). Only two of them underwent a complete CT study, and a single case was described in Italy (Fornaciari et al., 1989; Fornaciari, 2006; Cárdenas-Arroyo et al., 2019). As their modern counterparts, gallstones can be classified on the basis of their gross aspect, and subdivided into cholesterol-based and pigmented stones. Cholesterol-based stones represent the vast majority of gallstones and may be further classified as pure cholesterol (usually a single stone made of radiating crystals), mixed cholesterol-bilirubin-calcium (multiple, laminated), and composite cholesterol-bilirubin-calcium (crystals core surrounded by concentric rings) (Steinbock, 1990; Cariati, 2015). The development of cholesterol-based stones is predominantly diet-related, but metabolic, genetic, and endocrine factors may also be involved (Murphy et al. 2020; Lammert, 2022). Pigmented stones are black-brown friable concretions made of calcium bilirubinate usually depending on genetic factors, bile stasis, and microbial infection (Steinbock, 1990; Cariati, 2015; Murphy et al., 2020; Lammert, 2022).

The virtual autopsy (virtopsy) represents an extremely valuable approach to the conservative investigation of mummified bodies. Virtopsy allows osteological and extraskeletal analyses aimed at anthropological estimations, as well as at pathological findings and foreign objects documentation. Investigations are repeatable and data can be easily shared to digitally verify, discuss and reassess the findings (Uldin et al., 2017; Ejlskov Pedersen et al., 2021).

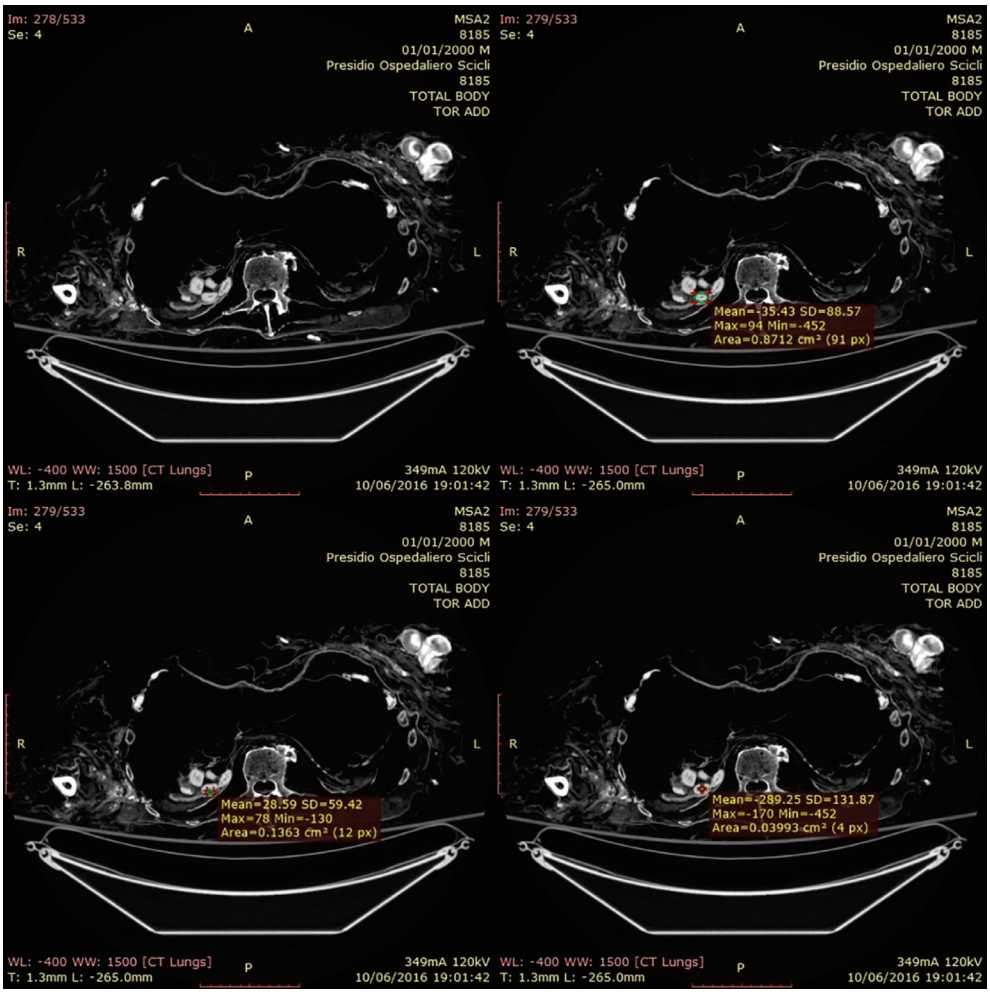

Figure 4. Tomodensitometric measurements of the gallstones.

The virtopsy approach allows a fully conservative bone and soft tissue detailed examination and has been used with good results by our group in another subject found in south-eastern Sicily (Ventura et al., 2022 a). Without a shadow of doubt, the use of fine-resolution devices is fundamental in obtaining virtual reconstructions of the bodies. The collection of radiologic data through high-quality, hospital-based CT scanners should be preferred to portable devices (Ventura et al., 2020, Profico et al., 2020). The analysis of DICOM files obtained from CT scans through the Anatomage table and Invivo 3D imaging software has been recently proposed and it may represent an extremely valuable option to reconstruct and virtually dissect mummified bodies (Salucci et al., 2024).

For conservative reasons, no endoscopic sampling of internal organs was allowed in Modica mummies, preventing us from performing further laboratory examination of the calculi. Important additional data on their structure, composition and microbial content could have been added by modern investigations of at least one of the stones (González-Reimers et al., 2018; Chen et al., 2019; Biehler-Gomez et al., 2019; Ventura, 2021; Long et al., 2022; Ventura et al., 2022 b). However, the detailed chemical composition of the gallstones could be inferred from densitometric measurements of CT scans. Tomodensitometric measurements may be of great help to that effect because HU ranges are highly specific for soft tissue calcifications.

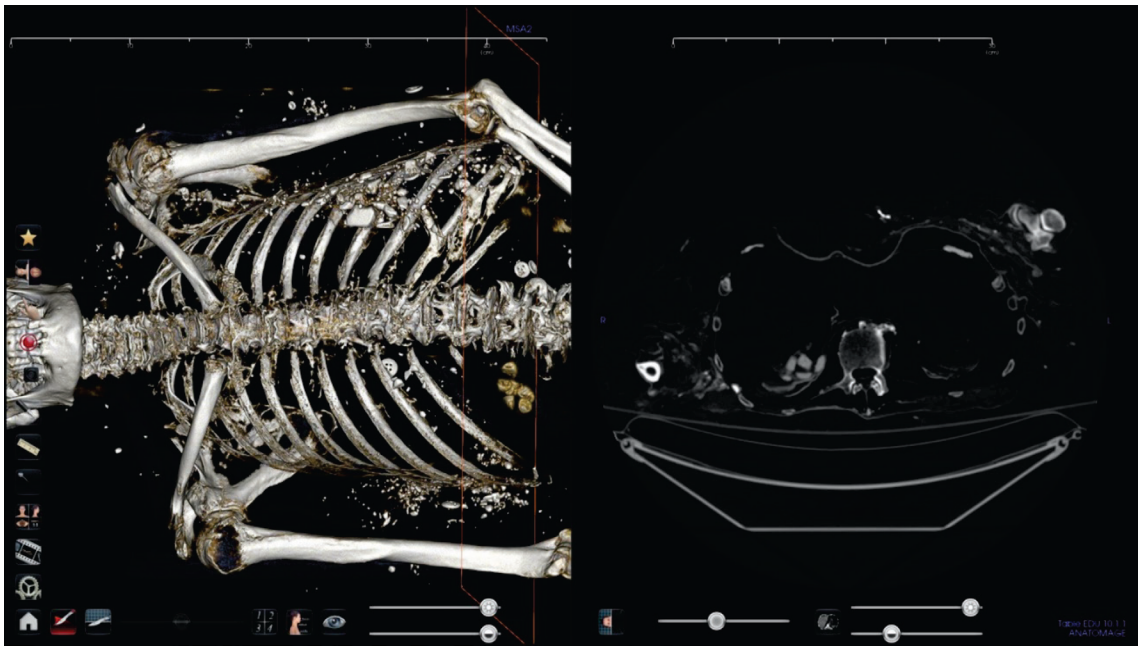

Figure 5. Virtopsy view of the gallstones with corresponding transverse CT scan.

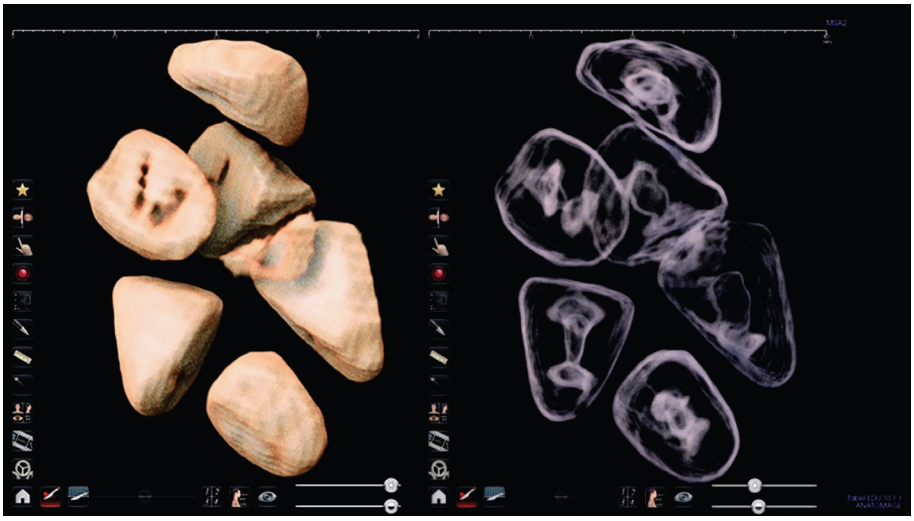

Figure 6. 3D renderings of the gallstones after virtual extraction from the body.

In modern clinical practice, it is important to identify the composition of gallstones because cholesterol stones can be treated by non-surgical means, namely pharmacological therapy with bile salts, extracorporeal shock wave lithotripsy, and contact dissolution therapy with methyl tert-butyl ether. For a successful non-invasive therapy, the identification of a high percentage of cholesterol with low calcium salts is important, as only these stones show satisfactory results (Bauer et al., 2010; Wee et al., 2021). Basically, CT facilitates the identification of radiolucent calcifications, such as cholesterol stones, that may be missed by conventional radiologic procedures. Tomodensitometry can then be used to distinguish hypo- or

isodense gallstones (below 50-60 HU), which respond to medical treatment, from hyperdense stones, which usually do not undergo complete dissolution (Caroli et al., 1992; Polverosi et al., 1992).

In our case, the low HU values allowed us to recognize a strong predominance of cholesterol with a low calcium percentage, ruling out pure pigment stones. The size, morphologic features, and multiplicity of the calculi were consistent with mixed cholesterol gallstones. The main exogenous risk factors for the development of cholesterol-based gallstones are represented by obesity, physical inactivity, diabetes mellitus, non-alcoholic fatty liver disease, as well as high calorie/carbohydrate intake, high glycemic load, and low fiber intake (Murphy et al., 2020; Lammert, 2022). These metabolic and dietary factors are in perfect agreement with the presence of cutaneous folds, the detection of pelvic phleboliths, and the high-quality clothing worn by the subject. All these bioanthropological and paleopathological findings indicate that this individual belonged to a high social class. Thus, the MSA2 subject could have been a nobleman or a member of the upper middle class.

Conclusion

Gallbladder stones can be easily identified in natural mummies using CT scanning with multiplanar and 3D reconstruction facilities. Tomodensitometric measurements according to the Hounsfield scale help to determine their chemical composition with excellent approximation. As its modern counterpart, ancient cholelithiasis was most frequently due to cholesterol-based stones and may thus represent a valuable bioanthropological marker of high social class. Finally, the presence of gallstones might also represent a valid clue for the identification of the subject, when information recorded in textual sources is available.

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