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INSIDE THE CASTS OF THE POMPEIAN VICTIMS: RESULTS FROM THE FIRST SEASON OF THE POMPEII CAST PROJECT IN 2015

by Estelle Lazer, Kathryn Welch, Dzung Vu, Manh Vu, Alain Middleton, Roberto Canigliula, Stijn Luyck, Giovanni Babino and Massimo Osanna[1]

The first casts of the forms of Pompeian victims of the AD 79 eruption of Mt Vesuvius were successfully achieved under the directorship of Giuseppe Fiorelli in 1863. To date, 104 individuals have been cast by restorers and archaeologists during the course of excavation. The methods used to obtain these casts were not well documented. It was always assumed that plaster or lime cement was merely poured into voids which preserved the impression of organic remains buried in the ash that covered the site during the catastrophe. It was also assumed that the undisturbed skeletal remains of victims were encased within the casts. The initial aim of the Pompeii Cast Project was to study these bones to build on and test the results of an earlier study of the large sample of Pompeian human remains that were disarticulated by post-excavation activities. Apart from providing information about the people who did not manage to escape the eruption, the project aimed to challenge previous interpretations of the lives and activities of these victims that were solely based on superficial inspection and circumstantial evidence.

Twenty-six casts were subjected to CT scanning or X-ray analysis in 2015. The results were unexpected. It was clear that the casts had been considerably manipulated. Bones were often removed prior to casting, and other elements had been introduced. This ongoing project has now been expanded to establish how these casts were achieved, to better understand nineteenth- and twentieth-century archaeological and restoration practice.

I primi calchi delle vittime pompeiane dell'eruzione del Vesuvio del 79 d.C. furono realizzati con successo sotto la direzione di Giuseppe Fiorelli nel 1863. Ad oggi, 104 individui sono stati fatti oggetto di calco negli scavi da restauratori e archeologi. I metodi utilizzati per ottenere questi "calchi" non sono stati sempre ben documentati. Si è sempre pensato che gesso o malta cementizia fossero semplicemente versati nei vuoti che avevano conservato l'impronta di resti organici, sepolti nella cenere che aveva ricoperto il sito durante la catastrofe. Si è anche dato per scontato che i resti scheletrici delle vittime fossero racchiusi all'interno dei calchi. Lo scopo iniziale del Pompeii Cast Project era quello di studiare queste ossa per incrementare e testare i

[1] The authors of this paper would like to thank the Pompeii Archaeological Park for granting access to the casts and assisting with this research; and, in addition, several colleagues and friends, including Greta Stefani, Sara Masseroli, Annalisa Capurso, Alberta Martellone, Bruno De Nigris, Valeria Amoretti (Pompeii Archaeological Park), Roger Pitcher, Kit Morrell, Peter Wilson and Margaret Harris (the University of Sydney). Stefano Vanacore, Girolamo Ferdinando De Simone, Sarah Court, Elena Mortelliti and Mary Beard have helped us greatly, and we thank them most warmly. Philips HC SPA Italia provided essential equipment. Our research has received generous financial support from the Faculty of Arts and Social Sciences (University of Sydney) and from Lion TV. The number assigned to each cast follows the catalogue numbers assigned by Professor Massimo Osanna.

risultati di uno studio precedente condotto su una grande quantità di resti umani pompeiani, disarticolati dalle attività successive allo scavo. Oltre a fornire informazioni sulle persone che non riuscirono a sfuggire all'eruzione, il progetto mirava a mettere in discussione le precedenti interpretazioni delle vite e delle attività di queste vittime che si erano basate esclusivamente su analisi superficiali e prove circostanziali.

Nel 2015 ventisei modelli sono stati sottoposti a scansione TC o ad analisi a raggi X. I risultati sono stati inaspettati. È ora chiaro che i calchi sono stati notevolmente manipolati. Le ossa sono state spesso rimosse prima della gettata e altri elementi sono stati introdotti nelle cavità. Questo progetto, ancora in corso, è stato ora ampliato per stabilire le modalità con cui i calchi sono stati ottenuti e per comprendere meglio le pratiche archeologiche e di restauro in uso nei secoli XIX e XX.

In 2015, 90 of the then 103 casts made of the forms of Pompeian victims of the AD 79 eruption of Mt Vesuvius were restored. The restoration formed an integral part of the Great Pompeii Project,[2] one of the aims of which is to deepen and disseminate knowledge of the site. Twenty-one of the restored casts were exhibited in the amphitheatre to showcase the results of the project.

As part of this project, our team subjected sixteen of the restored casts[3] to computed tomography (CT) scanning on site. We examined a further ten casts using a portable digital X-ray machine because their contorted poses or fragility prevented them from entering the gantry of the CT scanner.[4] The metal supports to which they were fixed limited our opportunities, but even under these conditions the X-ray study yielded significant results. This CT-scan and X-ray work constitutes the first season of the Pompeii Cast Project, which ultimately aims to investigate all the available casts of the Pompeian victims using CT scanning and digital X-ray technology.

BACKGROUND

On the basis of minimal information about the production of the casts of the Pompeian victims, it had always been assumed that they were achieved simply by pouring plaster into the voids that excavators found in the hardened ash layer, thus embedding complete skeletons as well as forming an accurate impression of each victim at the moment of death. Our initial aim was to build on the study of Pompeian human skeletons, most of which had been stored in two large ancient bath complexes.

The majority of skeletons available for analysis from Pompeii had become disarticulated. This was due to poor storage, a reflection of the low value afforded to the human remains as a scientific resource. Several studies had been undertaken in the nineteenth and twentieth centuries, most notably of the skulls (Lazer, 2009: 47–62). In 1986, Estelle Lazer began the process of sorting,

2 http://pompeiisites.org/en/the-great-pompeii-project (accessed 6 October 2020); https://whc.unesco.org/en/decisions/5091 (accessed 6 October 2020).

3 Catalogue numbers 04, 05, 08, 10, 21, 22, 34, 53, 57, 59, 60, 62, 63, 64, 66, 69.

4 These individuals are catalogued as numbers 01, 07, 09, 15, 50, 51, 52, 59, 61, 79.

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cleaning and analysing the majority of the available bones (Lazer, 1995; 1997; 2007: 609–16; 2009). She tested common assumptions about the Pompeian sample by means of statistical studies based on the analysis of individual skeletal elements. These assumptions included theories such as that the population must have been mixed because Pompeii was a river port and that the sample of victims was biased towards females, the elderly, very young people, and people with health issues. Such assumptions were found to be highly unlikely.

Skeletal analysis of the Pompeian sample is problematic. Diagnoses are more reliable with complete skeletons than with individual bones. Determination of pathology in the initial skeletal study had to be limited to cases that could be unequivocally diagnosed from a single skeletal element. We expected the casts to provide a large sample of complete skeletons encased in plaster. These embedded skeletons would not only provide information that could be used to test the results of previous research on isolated bones but also would yield information that could not be obtained from a disarticulated skeletal sample. This is because bone can only respond to insult in a very limited number of ways: bone can be lost, new bone can be laid down or there can be a combination of the two. By looking at the patterns of change across the skeleton, the likelihood of obtaining a reliable diagnosis is greatly increased. Our expectations were also based on the encouraging results we had obtained from the first radiographic study of a cast that was conducted in 1994 on the one victim that has been cast in resin (Cicchitti, 1993; Lazer, 2009: 260–4).

Another key aim of the project was to address the use of casts as props for storytelling. There is a long tradition of superimposing lives and personalities onto these victims of a mass disaster on the basis of superficial inspection and circumstantial evidence. For example, the sixteenth victim (Cast Number 15), which was cast in 1890, was thought to be a beggar on the basis of what appeared to be a bag for collecting alms in the left hand (Lazer, 2009: 251–2). This approach appropriates the actual life of this and other victims. Humans who were killed in a tragedy nearly 2,000 years ago deserve greater respect.

As our work progressed, we realized that the radiological investigation also offered a better understanding of the casting process.

THE ACQUISITION OF FORMS OF THE POMPEIAN VICTIMS

As mentioned above, the casting process during the nineteenth and twentieth centuries was not well documented. It has been asserted that casting of the Pompeian victims only became possible when the excavation strategy involved consistent stratigraphic digging in horizontal layers from top to bottom of the destruction layers. Cavities had been noticed in the compacted ash since the second half of the eighteenth century, and some forms of organic material, like wooden objects, had been successfully cast in plaster in the first half of the nineteenth century. According to historical sources, Fiorelli instructed his excavators to stop work whenever a cavity was found. The first successful cast of a human victim was achieved in February 1863. A brief description, stating that liquid plaster of Paris had been poured into the cavity, was reported in the *Giornale di Napoli* on 4 February. This was written a day after the discovery of the void. The forms of three more victims were discovered over the following days. Fiorelli published these discoveries in the *Giornale* on 12 February 1863. He stated that a cavity was found during the excavations on 3 February and that it was possible to remove some bones that were at arm's length within the cavity. He wrote that plaster was poured into this cavity and then left to set, revealing the form of a person that he interpreted as an adult male (Dwyer 2010: 42–8).[5]

Luigi Settembrini did not observe the creation of the first casts, but wrote what became a regularly quoted account of how they were made. He stated that before plaster was poured into the empty space, Fiorelli removed some bones with long tongs. According to his description, it was possible to see teeth in the mouth of the first victim after it was cast. Similarly, he described bones of the skull and fingers protruding from the plaster that encased the skeleton of the third victim (Dwyer, 2010: 48–52; Osanna, 2019: 316–17).

In the early years of the twentieth century, Spinazzola documented the casting process that was used during his directorship. His practice was to remove as many bones as possible from the cavities. His principal aim was to preserve the final moments of the victims, preferably in groups. Above all, he wanted to present the enormity of the disaster, as well as to provide information about how the victims perished and to reveal details about their clothing, spirit and character (Dwyer, 2010: 119).

During his long tenure as director of excavations in Pompeii and Herculaneum in the twentieth century, Maiuri was responsible for casting a number of victims. He too provided a brief description of the casting process. After careful exploration, one or more holes were cut into the compacted ash around the void. These holes were then probed and cleaned with a surgical tool shaped like a long spoon. After that, liquid plaster of Paris was poured into the cavity. The plaster was left to set for three days, after which the ash was removed to reveal the form of the victim (Maiuri, 1961: 659).

Although each director followed a slightly different process, the common view of how the casts were made was that it was simply done by pouring liquid plaster or cement into cavities when they were discovered.[6]

The 2015 field season offered the first detailed evidence that the casting process was much more complex than we had been led to believe. Our project had to be expanded to include a full study of the techniques that were used to obtain the forms of the Pompeian victims. This work is ongoing.

[5] For a more detailed account of the acquisition of the first casts of human Pompeian victims see Osanna 2019: 301–32.

[6] For example, Antonio D'Ambrosio, then at the Soprintendenza Archeologica di Pompei (pers. comm., 1994).

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MATERIALS AND METHODS

CT SCANNING

In September 2015, thanks to the generosity of Philips SPA Italia, a 16 Slice CT scanner was brought onto the site (Fig. 1). The equipment was installed directly outside the walls of Pompeii close to the amphitheatre so that the risk of damaging the fragile casts during transportation was minimized. In choosing the location of the installation, the technical team, with the advice of the qualified radioprotection expert, also assessed the risk of accidental exposure of any visitors to the radiation emitted by the equipment. In fact, the minimum possible distance for the passage was over 25 m. The temporary laboratory structure was made of wood with the integration of lead walls. The energy required for operation has been guaranteed by the use of a 120 KVA diesel generator set. An imaging diagnostic department was set up similar to a military field hospital.

The principal technical features of the Philips MX 16 EVO CT scanner are:

- Opening of the gantry: 70 cm
- Maximum scanning field of view (SFOV): 500 mm
- Longitudinal scanning: 1580 mm

Fig. 1. The CT scanner on the site of Pompeii in 2015 (photo: Roberto Canigliula).

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- Maximum bed load capacity: 200 kg (440 lb)
- Number of simultaneous layers: 16 × 0.75 mm
- Minimum 360° rotation: 0.5″
- Radius of tube: 5.0 MHU
- Focal spots: 0.5 × 1.3 mm (small); 10 × 1.3 mm (large)
- Generator: 50 kW
- kV switches: 90 kV and 140 kV
- Range of mA output: 30 mA–420 mA
- Acquisition Algorithm M.A.R. (Metal Artefact Reduction) to reduce artefacts from metal inclusions
- iDose4 iterative reconstruction algorithm
- DICOM 3.0

The gantry opening of 70 cm was the main limiting factor in determining which casts would be studied. The position of the limbs of a number of the victims when they were sealed in ash made it impossible for them to enter the gantry. The 200 kg (440 lb) weight limit of the bed of the scanner was not an issue.

Main post-processing methods

Acquiring the images was just the initial phase of the CT scan analysis. The most important part of this work was and is in post-processing the data. We chose the post-processing techniques best suited to increasing and diversifying the diagnostic content of the basic images. It was even necessary to create a specific acquisition protocol to obtain images that could be processed with minimal artefacts.

Once the capture processes were completed, the set of resulting sections could be superimposed and 'bundled' in order to create a virtual volume that associates the two classic axial image dimensions, a significant depth along the longitudinal axis of the object.

The editing of axial images was the main starting point for this optimization. Editing programs assisted the preparation of the axial images both individually and as predetermined sections (Slabs) by deleting those parts that were not required or by highlighting areas of interest by varying the density and, possibly, colour. This process allowed the creation of axial images that isolated areas of interest. The axial slices could then be processed using secondary reconstruction protocols. Based on the reconstruction program, we proceeded with two different analyses:

- Planimetry Analysis: the set of axial slices is rebuilt to obtain images along different planes.
- Volumetric Analysis: the set of axial slices is rebuilt to obtain a three-dimensional structure.

The MPR (Multiplanar Reconstruction) method allows planimetric analysis, the simplest data representation method. In this case, the axial sections are superimposed to create a virtual volume. This technique provides views of different planes, either standard, such as the sagittal, coronal, axial, or planes with angles and variable directions, like curved planes. This makes it possible to highlight the different structures lying on different planes, avoiding the need for complicated slice-by-slice analysis.

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Several reconstruction methods are available for Volumetric Analysis. These include maximum and minimum intensity projections, surface rendering, volume intensity projection, and volume rendering.

MIP (Maximum Intensity Projection) is a volumetric protocol with intentional information loss whereby a single two-dimensional image is obtained from a data volume with the same spatial orientation but with a selectively reduced information load (Dalrymple *et al.*, 1999). MIP images are obtained by displaying the maximum voxel attenuation values invested by a radius that crosses the object, represented by the digital volume, along a path set by the eye of the observer. This method is used to increase the precision of hyperdense structures (Perandini *et al.*, 2010).

MinIP (Minimum Intensity Projection) images are obtained similarly to MIPs, with the difference of taking the minimum of attenuation values of the voxels invested by the beam. This reconstruction method is distinguished by the ability to highlight low-density structures. MinIP is widely used when examining low-attenuation structures against a hyperdense background (Zompatori *et al.*, 1997).

3d-SSD is also known as 'surface rendering' and was the first volumetric reconstruction technique used to handle medical data. Quick and flexible in image rendering, the Shaded Surface Display is a process that, through an intermediate segmentation, enables reconstructed surfaces at the digital volume to form a three-dimensional image. Segmentation is simply an inclusion or exclusion of portions of the image, in such a way as to selectively highlight the structures of interest.

In the case of SSD, segmentation occurs by first selecting a threshold value as a threshold range and the program will automatically reconstruct an image with only voxels whose attributed value exceeds the threshold value, making the remaining voxels invisible. The fidelity with which the image is rebuilt depends in part on the selected threshold value (Gouraud, 1971). Surface rendering is not suitable for structures that do not have well-differentiated surfaces and only uses a small percentage of all available data (about 10 per cent).

There are tools to select and deselect parts of starting volume beyond densitometric differences, such as inclusion or exclusion of structures at the same density based on manual cut-out.

VIP (Volume Intensity Projection) is a technique that assigns the highest attenuation value to voxels that are closer to the observer, and lesser value to those that are more distant, thus providing information about the object's perspective (C. Fraga Piñeiro *et al.*, unpublished, 2013).

Volume Rendering: this algorithm works across the entire data volume by calculating the contributions of each voxel of the digital volume along a path set by the eye of the observer, and displays the composite result for each pixel. Volume rendering, unlike the SSD, provides data representation without using intermediate segmentation processes and provides high-fidelity reconstructions. There are several parameters in this technique, such as brightness and opacity, which can assist visualization or hide intrinsic details and interior details, enabling the user to parse the virtual object (Calhoun *et al.*, 1999).

The rendered parameters are applied to the entire collected data packet and modify the appearance of the image to be displayed, which means that volume rendering is extremely versatile for reconstructions. The most used parameters in the analysis of the casts were:

- Window width and Level: the width and level of the grey values window define a transfer function that associates the measured attenuation of each voxel with a corresponding value on the greyscale, which in turn is used to create the volumetric image.
- Opacity: that is, the degree with which nearby user structures obscure the structures that are more distant. The opacity values range from 0 per cent to 100 per cent. High opacity values produce a similar effect to surface rendering, which helps to visualize complex volumetric ratios clearly. Low levels instead allow the user to see through the structures, allowing an internal analysis of the object. Varying opacity has a non-intuitive secondary effect and varies object sizes: objects with high opacity values appear wider, whilst lower values make objects appear smaller.
- Brightness: this changes the appearance of the image by changing the values of each pixel of a certain percentage value. Like opacity, brightness can also range from 0 per cent to 100 per cent. The brightness value depends essentially on user preference.
- Percentage Classification: this is used to transfer functions on certain attenuation intervals within the volumetric data packet. For example, by assigning an opacity value equal to 0 per cent to voxels with a value of attenuation equal to 800 HU (bones), they will appear as transparent in the reconstructed image.
- The result of volume rendering is an RGBA format image, i.e. a volumetric dataset of four vectors, where the first three are the classic red (R), green (G), blue (B) colour components, and the last component represents opacity (A) (Shreiber, n.d.).

Data processing

The post-processing system used for this project is a Philips IntelliSpace IX console on which the volumetric images of the sixteen casts studied have been transferred. A parcel of about 2,000 axial 1 mm spiral images with pitch 1, 120 kV voltage, and 250 to 300 mAs currents was acquired on each scale. Every cast was assessed so that the most suitable post-processing techniques could be applied to each case. Post-processing enables the images of the skeletons and individual skeletal elements to be isolated and examined to provide information about sex, age-at-death, general health, population, lifestyle indicators and pathology. Measurement of the size, and evaluation of the density and morphology, of the skeletal remains will provide sufficient data for 1:1 scale 3D printing of the bones. The information derived from this study also enables reconstruction of the methods of production and restoration of the casts over time by STL files.

Since the plaster density is very similar to that of bone, it was not possible to use all post-processing procedures, in particular the MinIP, which has essentially been developed for the study of soft tissues. The great versatility of the settable rendering parameters of MIP, SSD, MPR and Volume Rendering enabled them to be widely used for reconstruction of the casts. Numerous VR presets have been created, optimized for the visualization of particular structures inside the casts in order to better distinguish the bones or objects from the density of the plaster present.

X-RAY ANALYSIS

As mentioned above, those casts that could not enter the gantry of the CT scanner were subjected to limited X-ray analysis. These casts were X-rayed in the course of one full night in September 2015 after the last visitors had left the site, to avoid exposing members of the public to radiation.

The key equipment employed for this project comprised a SPRINT AIR from the company SOUND, California, and an X-ray Generator from the company Veterinary X-rays, UK Algorithm settings by STL-International (exotic animals, archaeology and NDT).

The SOUND SPRINT AIR using Canon digital radiography detectors was selected for this project for its lightness, mobility, and flexibility in image processing. This mobile digital radiography (DR) system is normally optimized for equine or small animal use, but a new set of protocols and settings was developed specifically for use at Pompeii. The Canon detectors used are extremely sensitive and maintain the diagnostic image quality at reduced radiation dose. Interpolation from the level of doses needed during previous imaging at Pompeii allowed us to make new exposure charts and minimize overall radiation exposure while X-raying thicker body parts.

The software on the system features advanced image processing, which makes it possible to observe, in radiographs made through thick plaster, all the subtle details of trabecular bone structure and teeth. The image-processing parameters were created in a test lab using home-made test phantoms and were further optimized in-field after we obtained the first datasets.

Taking images with increasing kV settings and fine-tuning dynamic range, contrast and curve settings gave us a DICOM dataset that we could further manipulate and 'combine' into final images.

RESULTS

It is beyond the scope of this paper to present all the results of the CT scans and X-rays. Instead, we have chosen a sample of the casts as an indication of the possibilities the project offers and how it is being developed.

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CASE STUDIES

Nine of the casts that were subjected to X-rays and CT scans have been selected for discussion. They have been chosen because they highlight a number of issues that have already arisen and that we hope to address more fully when all the casts of Pompeian victims have been examined.

Cast Number 10

This individual was the tenth victim to be cast in plaster (Fig. 2). It was found with the ninth victim (Cast Number 09) at the northern end of the Via Stabiana in 1875 and was generally thought to be a woman. Some observers considered that 'she' had been pregnant at the time of the eruption. This individual inspired a great deal of literature, some of it erotic. The form of this cast was often compared to the Roman copy of the sculpture known as the Aphrodite Kallipygos that is displayed in the National Archaeological Museum in Naples (Garcia y Garcia, 2006: 191–2; Dwyer, 2010: 91–3; Capurso *et al.*, 2015a: 20; De Carolis and Patricelli, 2018: 56–61). The cast is almost completely devoid of bones. The thighs are supported and connected to the trunk by metal rods (one in the right and three in the left thigh). The prominent part of the abdomen, which has been described as evidence of pregnancy, has a different texture and radiodensity to the rest of the cast. There is a metal rod from the thorax to the head. At some point, one arm broke off and was subsequently reconnected. There is an observable difference in the hands of different archival photographs of this cast, but it is unclear when the break and restoration occurred (compare, for example, Dwyer, 2010: fig. 37; De Carolis and Patricelli, 2018: 60, fig. 41; and Figure 3 in this article.). The head rests on one forearm, which is the only part of the cast that contains skeletal elements.

Skeletal elements revealed

The proximal half of the right ulna and radius can be observed. The epiphyses appear to be fused. The distal ends of the bones are no longer extant. It appears that the hand and part of the forearm were lost and restored, as

Fig. 2. Cast Number 10 (photo: Estelle Lazer).

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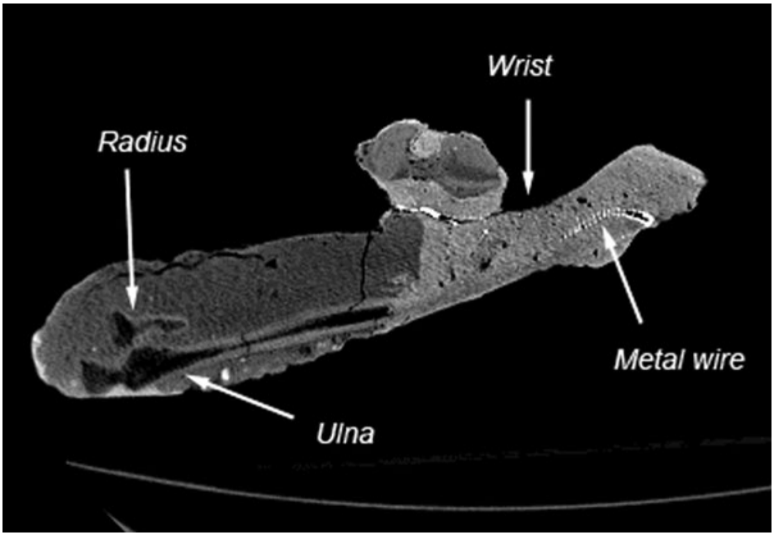

Fig. 3. Right radius and ulna of Cast Number 10 displaying fracture line and a different density of plaster where the region around the hand has been restored (photo: Philips/Roberto Canigliula/Dzung Vu).

evidenced by a clear fracture line and plaster of a different density, which has been attached to the original cast with a metal dowel. The shaft of the ulna extends beyond the fracture line of the original cast while the shaft of the radius ends at the fracture line (Fig. 3).

Interpretation

There is no clear evidence that this victim is female. The volume rendered image of the CT scanned cast does not display female features. The allegedly distended abdomen is probably a reflection of the impression of clothing that became bunched up when the victim fell during the eruption. The epiphyses of the radius and ulna appear to be fused, which indicates that the individual was an adult.

Cast Number 15

This victim was the sixteenth cast to be made (Fig. 4). The cast was produced in 1890, when the victim was discovered outside the Porta Stabiana. It has been interpreted as a male. A popular interpretation is that this person was a beggar with a bag for alms. The impression of a very fine sandal on one foot seemed a bit of a discrepancy but this was explained away as a gift from a philanthropist.[7] This victim was X-rayed. No bones were found in the head or the upper body.

[7] Garcia y Garcia, 2006: 193–4; Lazer, 2009: 251–2; Dwyer, 2010: 107–8; Capurso *et al.*, 2015a: 23; De Carolis and Patricelli. 2018: 69–70.

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Fig. 4. Cast Number 15 (photo: Estelle Lazer).

Skeletal elements revealed

Very little skeletal material was observed, but there was enough to appreciate that what had previously been interpreted as a begging bag was in fact a miscast hand. The lower legs and feet still survived. Metal rods were used to attach the lower parts of the legs to the upper parts and caused destruction of the knees.

The left foot is broken off from the distal parts of all proximal phalanges because a metal rod has been driven through it. The heads of metatarsals and bases of proximal phalanges are clearly visible, and they have all completely fused. The right foot has not been compromised by a metal rod and was therefore more readily studied. The distal end of the tibia shows almost complete fusion of the distal epiphysis. The distal end of the fibula is visible but not its epiphyseal line. The talus is clearly seen, with no visible epiphysis. The calcaneal epiphysis is not completely fused (Fig. 5). Multiple cracks were observed in these bones. They are typical of post-mortem damage on dry bones.

Interpretation

This individual was consistent in age with a person in their teens. There was almost complete fusion of the distal epiphysis of the right tibia. Fusion of this bone is usually complete in females between fourteen and sixteen years of age and males between sixteen and twenty. The right calcaneal epiphysis was not completely fused. In modern Western populations, fusion of this bone begins between ten and twelve years in females and eleven and fourteen years in males. It is generally completed between fifteen and sixteen years of age in females and eighteen and twenty years in males (White *et al.*, 2012: 395). Sex determination of sub-adults from the skeletal record tends to be unreliable (Lazer, 2009: 117–19).

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Fig. 5. Lower right leg and foot of Cast Number 15 displaying incomplete epiphyseal fusion of the calcaneus (photo: Stijn Luyck/Dzung Vu).

Cast Number 21

This individual was cast along with Cast Number 22 and other victims found in the garden of the so-called House of the Cryptoporticus (I.vi.2),[8] in 1914 (Fig. 6; Capurso *et al.*, 2015a: 25–6). Cast Numbers 21 and 22 were embracing but, as

[8] I.vi.2 here is part of a standard set of numbers used to reference specific buildings in Pompeii. The system was created by Giuseppe Fiorelli, who was director of Pompeii in the 1860s. They stand for region, insula or block. and house number.

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Fig. 6. Cast Numbers 21 and 22 (photo: Estelle Lazer).

they were cast separately, they could enter the gantry of the CT scanner individually. These two victims have variously been interpreted as two lovers or two women, sometimes as sisters or as a mother and daughter (Rocco, 2003: 127; De Carolis and Patricelli, 2018: 86–90).[9]

Skeletal elements revealed

The head section of the cast is fixed to the trunk by a metal rod, which extends from halfway down the head into the upper part of the trunk. The only portion of the skull that survives is a small strip of the squamous part of the occipital bone. No bone was observed in the neck and trunk.

The cast of the left upper arm is broken just above the elbow and contains no bone, just a rod encased in plaster, which has a slightly different structure and density than the surrounding plaster. The right arm had been broken from the trunk and was reattached with a metal rod. It contains a small bone fragment with no diagnostic features. There is no evidence of the humerus at the elbow, but the proximal ends of the radius and ulna could be observed. The epiphysis of the ulna had apparently fused with the shaft. The distal end of the radius appears to have been lost post-mortem. The distal end of the ulna and a few metacarpals could be discerned. There was no other evidence of the bones of the wrist and hand. It appears that fusion of the lower end of the ulna and the base of the visible metacarpals was completed.

[9] The preliminary results of DNA analysis of skeletal samples from these casts indicate that they were two unrelated males (D. Caramelli, pers. comm., 2019).

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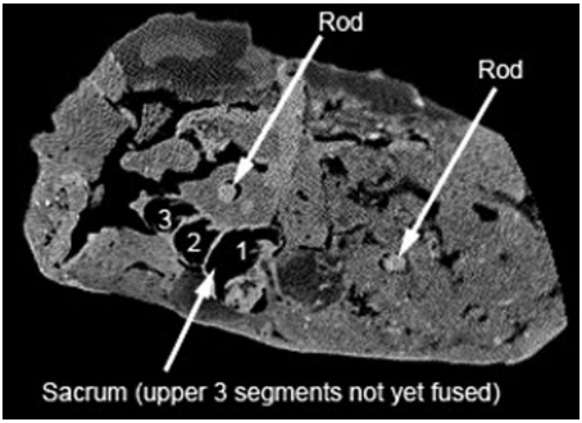

Fig. 7. Cast Number 21: sacrum with unfused upper three segments (photo: Philips/ Roberto Canigliula/Dzung Vu).

The proximal end of the right femur clearly displays the growth plates of the head and greater trochanter. It appears that fusion between the shaft and epiphyses had commenced. The lower half of the femur is no longer extant but there is an area where a few bones and bone fragments have been randomly accumulated, as if they fell to the bottom of the space while the plaster was still soft. The sacrum survives with its upper three sacrabrae not yet completely fused (Fig. 7).

More distally, an isolated distal end of a femur appears where the two lower limbs are still fused together with plaster. It was clearly broken after death, because it lies in a plane perpendicular to that of the body of the cast. The lower part of the left leg only contains a metal rod and a few unidentifiable bone fragments. There is a metal rod in the right leg, but the mid-shaft areas of both the tibia and fibula are identifiable. Near the lower end of the cast, a new metal rod appears just before the two bones abruptly end, each bone by an almost transverse fracture, certainly due to post-mortem handling. These leg bones do not help in the evaluation of age because they lack the articular ends where the state of fusion of epiphyseal growth plates could be observed.

Interpretation

There is insufficient evidence to establish the sex of this individual. Also as a sub-adult, skeletal evidence would not be that reliable. Some features of some bones are compatible with the skeletal age between fourteen and eighteen years.

It appears that the epiphyses of the right ulna have fused with the shaft and that the base of the visible metacarpals on the right hand have also fused. In modern Western populations, fusion of the proximal end of the ulna usually occurs at around twelve to fourteen years in females and thirteen to sixteen in males, while fusion of the distal end of the ulna generally occurs around seventeen years of age in females and seventeen to twenty in males. The sacrum survives

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with its upper three sacrabrae not yet completely fused. Fusion of the sacrabrae usually occurs around the age of twelve to fourteen years (White *et al.*, 2012: 391, 395).

However, it must be noted that the only features in the CT study that are identified with absolute certainty are the growth plates in the proximal end of the femur which are not yet completely fused. That gives more weight to the age estimation of fourteen to sixteen years if the victim is a female, and fourteen to nineteen years if the victim is male.

Cast Number 22

This individual was cast, along with Cast Number 21 and other victims found in the garden of the so-called House of the Cryptoporticus (I.vi.2) in 1914.

Skeletal elements revealed

The cast has many post-mortem fractures, and metal rods appear to have been used just to reinforce repairs. Most of the skull is preserved, but the majority of the right half of the mid-face part of the skull was badly damaged, perhaps as a result of post-mortem handling. However, most of the jaws were preserved. The cast of the head and neck is broken in places, and a tubular metal rod was used to reinforce the head and neck parts of the cast.

The rod introduced to repair the break of the cast broke off the right part of the skull base, including part of the temporal bone and the condyloid process of the mandible, and pushed it up to the top left-hand side of the cranial cavity. The bodies of some cervical vertebrae were also pushed up into the head by the rod.

The skull cap (calvarium) and skull base are well preserved and even the very fine details of the temporal bone are well defined. Lambdoid ossicles and Wormian bones were observed in the lambdoid suture (Fig. 8). The mastoid process has developed in height. There is complete fusion of the junction between the central and lateral parts of the base of the occipital bone, and fusion of the spheno-occipital synchondrosis.

The dentition is apparently that of an adult, though some of the third molars have not yet erupted. There is some post-mortem damage to the jaws, with distal sections of the mandible being lost. The lower left molars and the lower right canine, premolars and molars cannot be found. The upper right wisdom tooth (18) is unerupted.[10] The upper right canine (13) and lateral (12) sockets are present with no teeth. They were possibly lost at or around the time of death, though it is more likely that they were lost post-mortem. A tooth shaped like a canine was observed in the CT scan in the vicinity of the upper right first molar. It is probably the upper right canine. The upper left central tooth is missing, probably post-mortem. The upper left premolars (24e and 25m) show

[10] The dentition is described according to the FDI (World Dental Federation) system of nomenclature.

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Fig. 8. Skull of Cast Number 22 displaying ossicle at lambda and lambdoid ossicles in the lambdoid suture (photo: Estelle Lazer).

signs of caries or tooth decay. The upper left first molar is missing. It is impossible to assess whether this occurred before or after death due to the post-mortem bone loss in the region. The upper left third molar (28) appears to be unerupted.

The vertebrae are damaged, but surviving parts demonstrated a complete fusion of the vertebral/neural arch with the vertebral body. The dens or odontoid process of the axis (the second cervical vertebra) is complete.

The entire thorax part of the skeleton is absent from the cast. There are no bones in the right upper limb, just a metal rod. Only a short segment of the left upper limb could be scanned. Unfortunately, the articular ends of the bones of this arm, which would have provided information about age-at-death, did not fit in the gantry of the CT scanner. No bones were observed in the abdomen and the pelvis is absent.

The cast of the left lower limb has been broken from the body at some stage and reattached with a short metal rod. The entire left femur survives, though the head and neck have been fractured post-mortem. The proximal and distal epiphyses have fused with the shaft. The knee and proximal ends of the tibia and fibula are not clearly visualized in the scan. Only the middle part of these two bones is clear. The distal end of each bone and the ankle are not clearly defined, partly because of the angle of the plane of the CT image, and partly because the ankle and foot have broken off and were reattached with a metal rod. There is no detail at the ends of the tibia and fibula and at the ankle, so the state of fusion of the epiphyses at these sites cannot be evaluated for age estimation.

The right lower limb of the cast broke off and was reattached to the trunk with a long metal rod that extends from the right buttock down to the ankle. The latter was also separated then reconnected to the leg. There is no femur and only the mid-shafts of the lower leg remain. What appears to be the ankle and foot in fact contains only a few bones; probably lumbar vertebral bodies that broke off and displaced into this part of the cast.

Interpretation

The bones that could be interpreted were consistent with those of an adult. There is complete fusion of the junction between the central and lateral parts of the base of the occipital bone, and fusion of the spheno-occipital synchondrosis. This fusion is usually complete by fifteen years of age. The epiphyseal plates of the greater trochanter and of the distal end of the femur (the femoral condyle) have completely fused with the shaft, indicating that the victim must have been at least seventeen to eighteen years of age. The dentition suggested that this might be a younger adult as the surviving third molars had not erupted (Lazer, 2009: 149; White *et al.*, 2012: 385–6, 395).

The pelvis, which contains the key features for sex differentiation, does not survive on this cast. The features of the skull, which are not the most reliable for sex determination, especially for the Pompeian sample, can be used with caution to provide some clues about the possible sex of this victim. The features of the skull tend to be more gracile than robust, which suggests a female rather than a male. The mastoid process is not prominent, the arch of the palate is short and parabolic in shape and the opening of the orbit is round and large relative to the face (Lazer, 2009: 127–30; White *et al.*, 2012: 408–13). However, it must be stressed that no sex attribution can be made with confidence based solely on these features.

Cast Number 50

This victim (Fig. 9) was found with Cast Numbers 53, 52 and 51. These victims were discovered in 1974 at the foot of the staircase that led to the garden and seafront in the so-called House of the Golden Bracelet (VI.xvii.42). It was suggested that they were trying to escape to the port when they were killed by the pyroclastic surge (Rocco, 2003: 153–62; Capurso *et al.*, 2015a: 32). The pose of Cast Number 50 did not allow it to enter the gantry of the CT scanner, and only a limited X-ray analysis of the skull was performed.

Skeletal elements revealed

The head appears to have been broken from the body and is now connected to the rest of the cast by three metal rods (Fig. 10). There has been considerable damage to the skull. The orbital margins appear to be rounded rather than sharp, which is a male feature, but the supraorbital ridge, another feature associated with male attribution, is not prominent (Lazer, 2009: 127–30; White *et al.*, 2012: 408–14). The upper and lower teeth are preserved, although the mandible and maxilla were fractured post-mortem and displaced.

The most useful information was obtained from the dentition. This individual has an established dentition with all teeth present. The wear is not excessive, which, when compared with other cases in the Pompeian sample, would

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Fig. 9. Cast Number 50 (photo: Estelle Lazer).

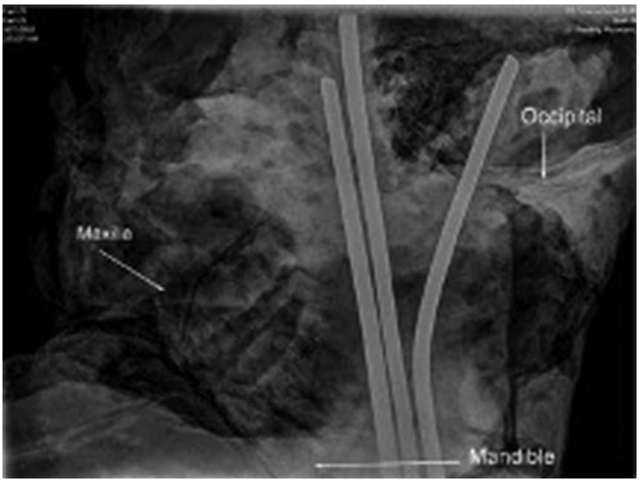

Fig. 10. X-ray of Cast Number 50 showing metal rods used to attach the head to the body and dentition (photo: Stijn Luyck/Dzung Vu).

indicate that this is a younger adult (Lazer, 2009: 150–1). There is no evidence of decay in the teeth of this person.

Interpretation

It is not possible to make a reliable attribution of sex to this individual from two features of the skull. The orbital margin and supraorbital ridge did not provide

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Fig. 11. Cast Number 51 (photo: Estelle Lazer).

consistent information about the sex of this person. The only available feature for estimating age-at-death was the dentition, which suggests a younger adult.

Cast Number 51

This victim (Fig. 11) was found apparently standing on the hips of Cast Number 52 and in association with Cast Numbers 52 and 53 (Rocco, 2003: 153–62; Capurso *et al.*, 2015a: 32).

Skeletal elements revealed

The area that makes up the head is mostly composed of solid plaster with just a small piece of posterior calvarium (Fig. 12).

There is evidence of mixed primary and secondary dentition amongst the erupted teeth. The lower primary incisors are all missing. They may have been lost prior to death or were so loose that they fell out when the mandible dropped to its current position. The radiographic views preclude the ability to position them in relation to the long axes of the teeth in the jaw, so it is impossible to establish the stage of eruption of the permanent incisor teeth at the time of death. There is apparent crowding of these incisor teeth in the jaw as these teeth are positioned at angles to the arch form, apparently to fit into the available space. Essentially the two lateral incisors (32, 42) are lingually placed behind the two central incisors (31, 41) (Fig. 13).

The trunk of the body appears to be broken just below the level of the abdomen, and the lower part of the body has been reconstructed with and filled with what appear to be bricks and fixed to the rest of the cast with two

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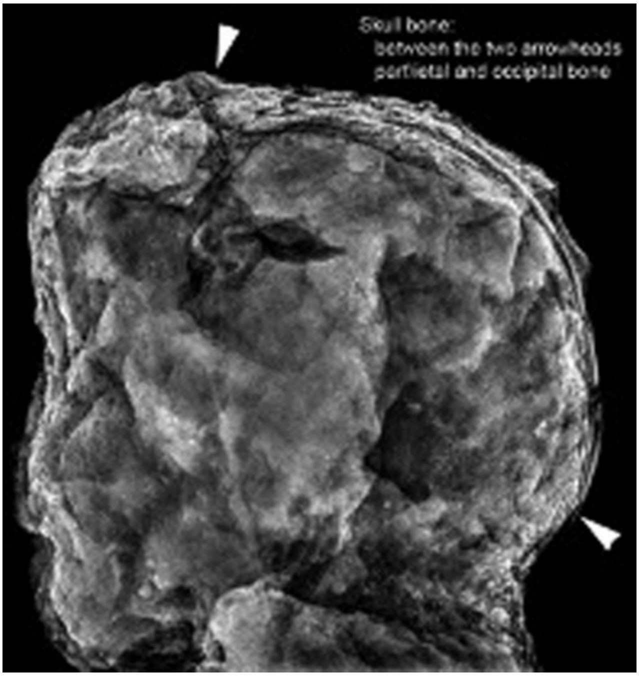

Fig. 12. Head of Cast Number 51 with arrows pointing to areas of bone (photo: Stijn Luyck/Dzung Vu).

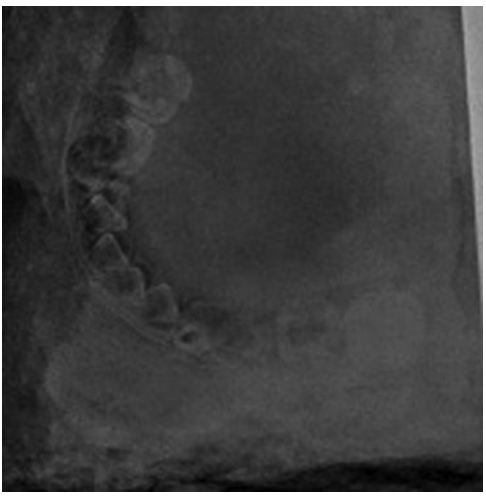

Fig. 13. Mandible of Cast Number 51 as found in the body cavity (photo: Stijn Luyck/Dzung Vu).

metal rods. The trunk is filled with plaster, and the only apparent skeletal element is a mandible at the bottom of the upper trunk section. There appear to be some adult bones lodged in the lower fragment of the trunk and cast.

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Interpretation

As mentioned above, it is extremely difficult to determine sex of children from skeletal evidence. The mixed dentition observed in the mandible indicates an age-at-death of at least five to six years, depending on the sex of the individual (White *et al.*, 2012: 385–6). The extensive reconstruction of the lower torso indicates that more research is required to understand how this cast was achieved.

Cast Number 52

This victim (Fig. 14) was found with Cast Numbers 50, 51 and 53 (Rocco, 2003: 153–62; Capurso *et al.*, 2015a: 32). As in the case of Cast Number 50, this victim, which is attached to Cast Number 51, could not enter the gantry of the CT scanner and so was subjected to limited X-ray analysis.

Skeletal elements revealed

The head is reinforced by two large metal rods. The skull presents as that of an adult with a number of post-mortem fractures (Fig. 15).

The teeth are well preserved. This individual presents with mature adult dentition. Observed wear facets on the teeth are not extreme and are consistent with younger middle age as compared with other cases that have been examined. There appears to be ante-mortem tooth loss of the second premolar and first molar of one side of the maxillary arch, with the second molar apparently tilted mesially, ostensibly having migrated to fill the gap (Fig. 16).

Only the stumps of the metacarpals of the hand remain in the cast. Although some are fractured, the bases are clearly seen. The epiphyses of the bases of

Fig. 14. Cast Number 52 (photo: Estelle Lazer).

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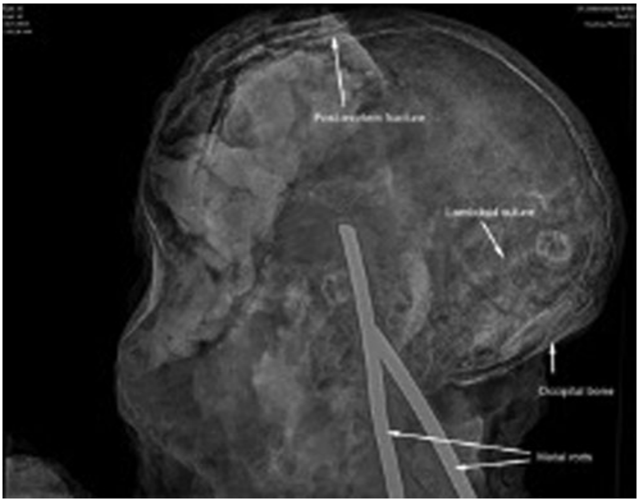

Fig. 15. View of the skull of Cast Number 52 showing some of the key landmarks and the metal rods that were inserted during the casting process (photo: Stijn Luyck/Dzung Vu).

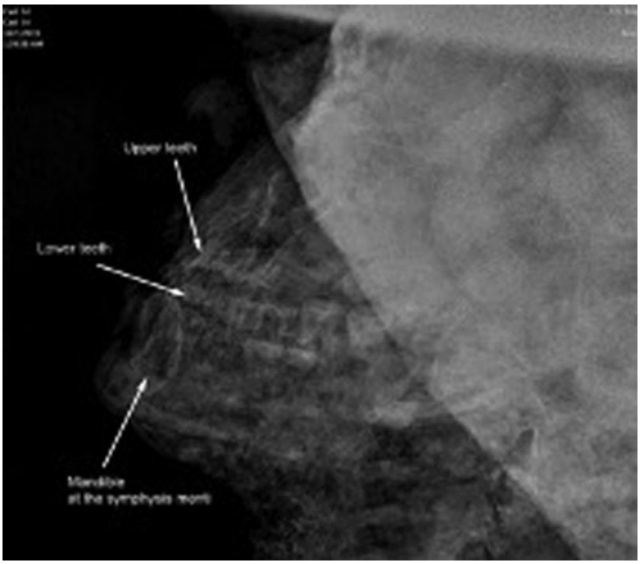

Fig. 16. Dentition of Cast Number 52 (photo: Stijn Luyck/Dzung Vu).

metacarpals generally fuse between the ages of fourteen and sixteen years (White *et al.*, 2012: 395).

Interpretation

This individual is clearly a mature adult, but there is insufficient evidence to make an attribution of the sex of this victim.

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Cast Number 53

As mentioned above, this victim (Figs 17 and 18) was discovered in 1974 with three other skeletons (Cast Numbers 50, 51 and 52) at the foot of the staircase leading to the garden and seafront in the so-called House of the Golden Bracelet (VI.xvii.42). The group was interpreted as a family because the four victims were found in close proximity to each other. They comprise two adults and two children. Cast Number 50 has been interpreted as a male purely on the basis of visual inspection, and Cast Number 52 as female simply because there is a child (Cast Number 51) on their lap and they sported a heavy gold bracelet on one arm. It has been suggested that Cast Number 53 may have been cast in 1978, after the other three victims. Much more detail can be observed on this cast and it appears to be much more realistic than the other three in this group (Rocco, 2003: 153–62; Capurso *et al.*, 2015a: 32; De Carolis and Patricelli, 2018: 104–5). This group is currently being subjected to a DNA investigation, which is yielding results that do not support the earlier interpretations (D. Caramelli, pers. comm., 2019).[11]

This individual has been traditionally interpreted as a boy, on the basis of a bulge in the plaster in the area of the genitalia (Rocco, 2003: 153–62; Capurso *et al.*, 2015a: 32).

Skeletal elements revealed

The CT scans reveal a reasonably well-preserved skull with the right half of the skull being larger than the left half in width and height. The right side of the mandible displays post-mortem damage, and its vertical part, the ramus, is missing. The anterior and posterior fontanelles are closed. The occipital bone is not completely formed. There is partial fusion of the suture between the lateral and squamous parts of the occipital bone (Fig. 19). The lateral and basilar parts of the occipital bone are still separated. The temporal bone development is consistent with that of the occipital bone. The mastoid process is still short and has not extended below the base of the petrous portion of the temporal bone.

The dentition is that of a child. No secondary teeth have erupted and no primary teeth have been lost.

All the cervical vertebrae are damaged. Only portions of a few neural arches can be identified with some confidence. Those that survive display fusion of the two halves of the neural arch, which is clearly separated from the centrum. It is worth noting that the majority of the centra are missing.

In addition, most of the thoracic vertebrae show signs of post-mortem damage, with the spinous processes all broken just posterior to the base. The neural arches are complete, with fusion of the halves of the spinous processes. The neural arches are all separated from the centrum (many of the latter are missing or incomplete).

[11] The preliminary results indicate that all the victims in this group are unrelated males.

Fig. 17. Cast Number 53 (photo: Estelle Lazer).

Fig. 18. Volume rendered surface reconstruction of Cast Number 53 (photo: Philips/ Roberto Canigliula).

Many of the spinous processes of the lumbar vertebrae are also broken. As in the case of the cervical and thoracic vertebrae, the neural arches are complete, with fusion of the halves of the spinous processes. Most of the centra are

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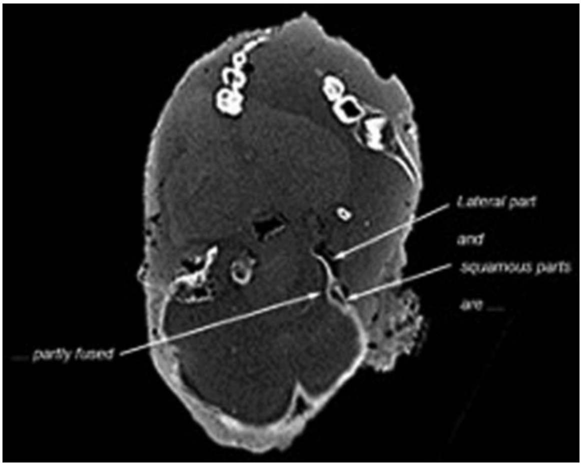

Fig. 19. Section through the skull of Cast Number 53 displaying partial fusion of the lateral and squamous parts of the occipital bone (photo: Philips/Roberto Canigliula/ Dzung Vu).

incomplete, but fusion of some of the neural arches to the centra can be observed (Fig. 20).

The three parts of the pelvis, ilium, ischium and pubis, are all separate and the acetabular area is not defined. The tarsal bones are all visible, but no epiphyses of tarsal bones were apparent (Fig. 21).

No signs of pathology were observed on the bones of this individual. As with the majority of the scanned casts, post-mortem fractures were evident.

Interpretation

With respect to the skull, the closure of the anterior and posterior fontanelles usually occurs around two years of age in modern Western populations. Fusion of the lateral and squamous parts of the occipital bone usually progresses from the first to the third year of life. Fusion of the lateral and basilar part of the occipital bone usually only commences at around five years of age. The mastoid process begins to grow from the fifth until the seventh year of life. The bone development of the skull suggests an age between one and three years and less than five (White *et al.*, 2012: 52–3, 63, 66, 70, 74, 77, 91, 95).

Not all developing secondary teeth are visible, so there are limitations to the age estimation from the dentition. The likely age at death would be between two and three and a half years, with the evidence indicating an age closer to three years (White *et al.*, 2012: 385–6).

Fusion of the neural arches in all the vertebrae also suggests an age-at-death greater than two years. The separation of the neural arches from the centra indicates an age of less than three years, which is when fusion generally begins in both cervical and thoracic vertebrae. The observed fusion of some of the neural arches to the centra in the lumbar vertebrae indicates an age greater than

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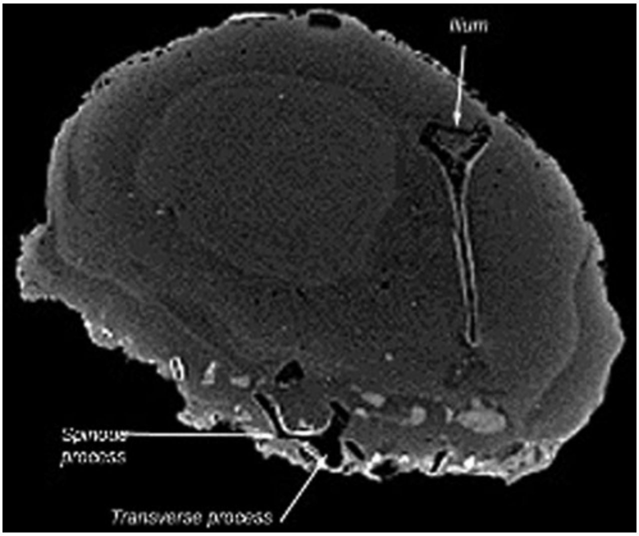

Fig. 20. Section showing lumbar vertebrae of Cast Number 53 (photo: Philips/Roberto Canigliula/Dzung Vu).

Fig. 21. Right leg and foot of Cast Number 53 (photo: Philips/Roberto Canigliula/Dzung Vu).

two years at the time of death as this fusion usually commences at around two years of age (White *et al.*, 2012: 135).

The separation of the ilium, ischium and pubis, along with the lack of definition of the acetabulum, is consistent with an age attribution under four

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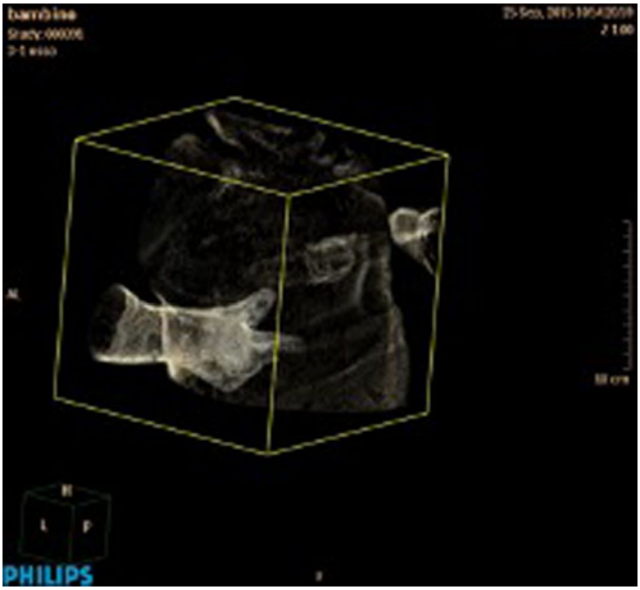

Fig. 22. Image displaying apparent belt buckle on chest of Cast Number 53 (photo: Philips/Roberto Canigliula).

years. The presence of tarsal bones indicates an age of at least three years, but the lack of epiphyses suggests that this individual was less than five years of age (White *et al.*, 2012: 233, 283).

The overall evidence suggests an age consistent with about three years in a modern Western individual.

Likewise, it is extremely difficult to determine sex from juvenile skeletons without recourse to nuclear DNA analysis. The male attribution on the basis of a bulge in the plaster cast in the region of the genitalia is spurious as it is not very clear and it is impossible to ensure that this is not an artefact of the casting process. At present there is insufficient evidence to make an unequivocal attribution of sex of this individual from gross inspection of the skeletal evidence (Lazer, 2009: 117–19).[12]

The CT scan revealed what appeared to be a belt buckle embedded in the plaster at the level of the chest of this victim, along with the impression of clothing. It appears likely that the clothing bunched up as the child fell, with the result that the belt was pushed up onto the chest (Fig. 22).

Cast Number 08

The dog was the eighth victim to be cast. It was said to have been found chained to the entrance of the so-called House of Vesonius Primus (VI.xiv.20), also known as the House of Orpheus, in 1874. It evoked a number of sentimental descriptions,

[12] The DNA evidence does suggest that this individual was a male.

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Fig. 23. Volume rendering and MIP images of Cast Number 08 (photo: Philips/ Roberto Canigliula).

the most popular being that of a faithful pet unable to escape (Garcia y Garcia, 2006: 191; Dwyer, 2010: 87–9; Capurso *et al.*, 2015a: 19; De Carolis and Patricelli, 2018: 62). It is one of only three non-human mammals to have been cast in plaster to date.[13]

[13] A pig found at a working farm was cast in 1977 and two horses were discovered in association with a villa to the north of Pompeii, one of which was cast in 2018.

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Skeletal elements revealed
It appears that all the bones were removed prior to casting. This is the only cast studied so far that has not yielded any skeletal elements.

Interpretation
The CT scan shows the original bronze rings where the chain would have been attached to the collar, as well as metal reinforcing rods and some restoration work. Volume rendering (Fig. 23) reveals areas of different densities of plaster that indicate that it was either assembled from at least six pieces or that it was restored with new plaster over time.

DISCUSSION AND CONCLUSIONS

The first *in situ* CT scanning and X-ray analysis of 26 of the 86 casts that were restored in 2015 demonstrated that our methodology and equipment are suitable for a continuation of this study. It should be noted that ongoing developments in scanning and X-ray technology will ensure that the resolution of imaging will improve as we work on our project.

We were initially surprised to find that none of the casts we studied in 2015 had complete skeletons embedded inside them. The preliminary study undertaken in 1994 on the resin cast from Oplontis revealed an entire and almost perfectly articulated skeleton (Lazer, 2009: 260–4), which led us to expect that we would be working with complete skeletons. The limited documentation of the casting process in the nineteenth and twentieth centuries provided some explanation of the lack of bones in casts, but the available literature did not give the impression that quite so much skeletal material had been removed prior to casting.

All of the casts that were scanned and X-rayed in 2015, with the notable exception of the dog, contained some skeletal elements. This led to an expansion of our research programme to understand better how the casts were achieved, from the first casts in 1863 right up to the present.

Before we commenced this project, we already appreciated that the casts had at times been creatively restored. The people who made and restored them also restored sculptures and it is increasingly evident that there is some artifice in the creation of these forms of victims.

While some casts were made by people with little or no technical training, restorers who traditionally had a background in sculpture and other arts appear to have perfected techniques for 'finishing' each cast. It is telling that there do appear to be stylistic differences between casts produced in different periods. These are substantial enough to enable a number of the casts to be datable purely on the basis of visual inspection.

The casts made during the time of Fiorelli's directorship, especially during the 1870s when the casting techniques became well established, tend to have relatively well-defined and naturalistic features. Good examples from this period are Cast Number 07 which was made on 25 September 1873 and Cast Numbers 09 and 10 which were produced on 23 April 1875.

By comparison, the casts made under the regime of Maiuri tend to have far more schematic features; faces are minimally defined, with depressions to mark the eyes and slashes to demarcate mouths. Examples can be seen amongst the thirteen victims that were cast in the Garden of the Fugitives (I.xxi.2) during April and May 1961 (Cast Numbers 35–47) and the three individuals who perished on a staircase in the House of Fabius Rufus (VII.xvi.22), that were cast in November 1961 (Cast Numbers 48 and 49 – the third cast can no longer be found).

The amount of detail that survived on casts was highly dependent on the conditions associated with the material that encased each victim and there was considerable variation between the casts of individuals. It is clear that far more than minor imperfections associated with the casting technique were creatively restored. It seems plausible that the simplified features of the twentieth-century casts resulted from the influence of contemporary art, whilst the nineteenth-century restorations tended to be more naturalistic, which in turn was a reflection of the art of that period. It should be noted that the observed stylistic differences over time are more likely to be a function of the traditions of the restorers of an era than the artistic sensibilities of a particular director of the excavations (Lazer, 2009: 254–5).

Though it is disappointing that the majority of casts we examined in 2015 appear to lack complete skeletons, the bones that survive still provide us with enough evidence to test the results of Lazer's study of the disarticulated skeletal sample. The results obtained from these casts are consistent with the original key results. For example, very few cases of healed trauma were found amongst the disarticulated skeletal sample and no cases of healed or peri-mortem fractures were observed on the bones of the casts. The dental data from the disarticulated skeletal sample indicated that there were significant oral health problems, such as ante-mortem tooth loss, periodontal disease and caries. These have been observed in some of the casts that we studied, such as Cast Number 22. This suggests that these victims may have suffered from systemic conditions, like cardiovascular disease, diabetes, gastric or respiratory disorders (Lazer, 2009: 265–71; 2016: 142–3; Meyer & Fives-Taylor, 1998: 88–95; Molloy et al., 2004: 625–32; O'Reilly and Claffey, 2000: 13–18).

Non-metric traits have proved to be useful population indicators for the Pompeian sample. The extremely high frequencies of some traits, like palatine torus and double-rooted canines, compared to other populations suggests a certain level of homogeneity, either as a result of shared genes or a common environment during the years of growth and development. This discovery is at odds with the traditional view that the Pompeian population was heterogeneous because Pompeii was a river port (Lazer, 2009: 221–46).

The presence of relatively large ossicles at lambda and Wormian bones in the lambdoid suture of Cast Number 22 is consistent with observations on the disarticulated Pompeian sample. Ossicle at lambda was present on 20.2 per cent of the Pompeian sample, while lambdoid ossicles were found on 34.8 per cent of the left side and 39.3 per cent of the right side of the lambdoid suture of the Pompeian sample. It is notable that these results are not mirrored in the Herculaneum skeletal sample (Lazer, 2009: 237–40, 245–6).

Nonetheless, the interpretation of non-metric skeletal traits is problematic due to the difficulty of assessing whether individual traits reflect genetic or environmental factors, or a combination of the two. It will be interesting to compare these results with those obtained from DNA analysis of the Pompeian skeletal remains.

Perhaps, in the end, the key issue that the Pompeii Cast Project will address is the use of casts as props for storytelling. The work we have done is already enabling us to rewrite some of the myths associated with specific casts. Despite the fact that we are dealing with a compromised skeletal sample, we have already been able to reinterpret the individuals who became cast numbers 28 and 77. It is clear that Cast Number 10 was not a pregnant female and that Cast Number 15 was a young individual who had not yet reached adulthood, rather than the crippled old beggar that some have claimed.

This project aims to find out what we can about every individual whose form is preserved in a cast and thereby to fix our attention on the life they had rather than the one assigned to them by superficial observation. This will give them the respect they deserve as humans who were killed in a tragedy nearly 2,000 years ago.

GLOSSARY

(*see Figure 24 for further information*)

acetabulum The portion of the hip joint formed by the coxa. It is the socket, which articulates with the head of the femur.

axial skeleton The skull, vertebrae, ribs, sternum and sacrum.

basilar base (of the skull). This term is also used to describe the suture on the base of the skull between the occipital and the sphenoid.

calvarium The portion of the skull containing the brain, namely, the cranium. This term refers to the area above the supraorbital ridge and the superior nuchal line and does not include the facial skeleton.

canine tooth Single-rooted tooth between the lateral incisor and the first premolar.

caries Decay, resulting in the softening, discoloration and destruction of a tooth. It involves the decalcification of enamel or dentine.

cervical This term relates to the neck. The vertebrae of the neck are known as the cervical vertebrae. This word is also used to describe the margin between the root and crown of a tooth (also known as the cervicoenamel line or junction (CEJ)).

cranial Towards the head.

cranium The skull without the mandible or hyoid bone.

CT scans Computed (axial) tomography (CT) scans were developed by Hounsfield in 1972. This technique enables computerized image reconstruction from a series of cross-sectional X-ray scans.

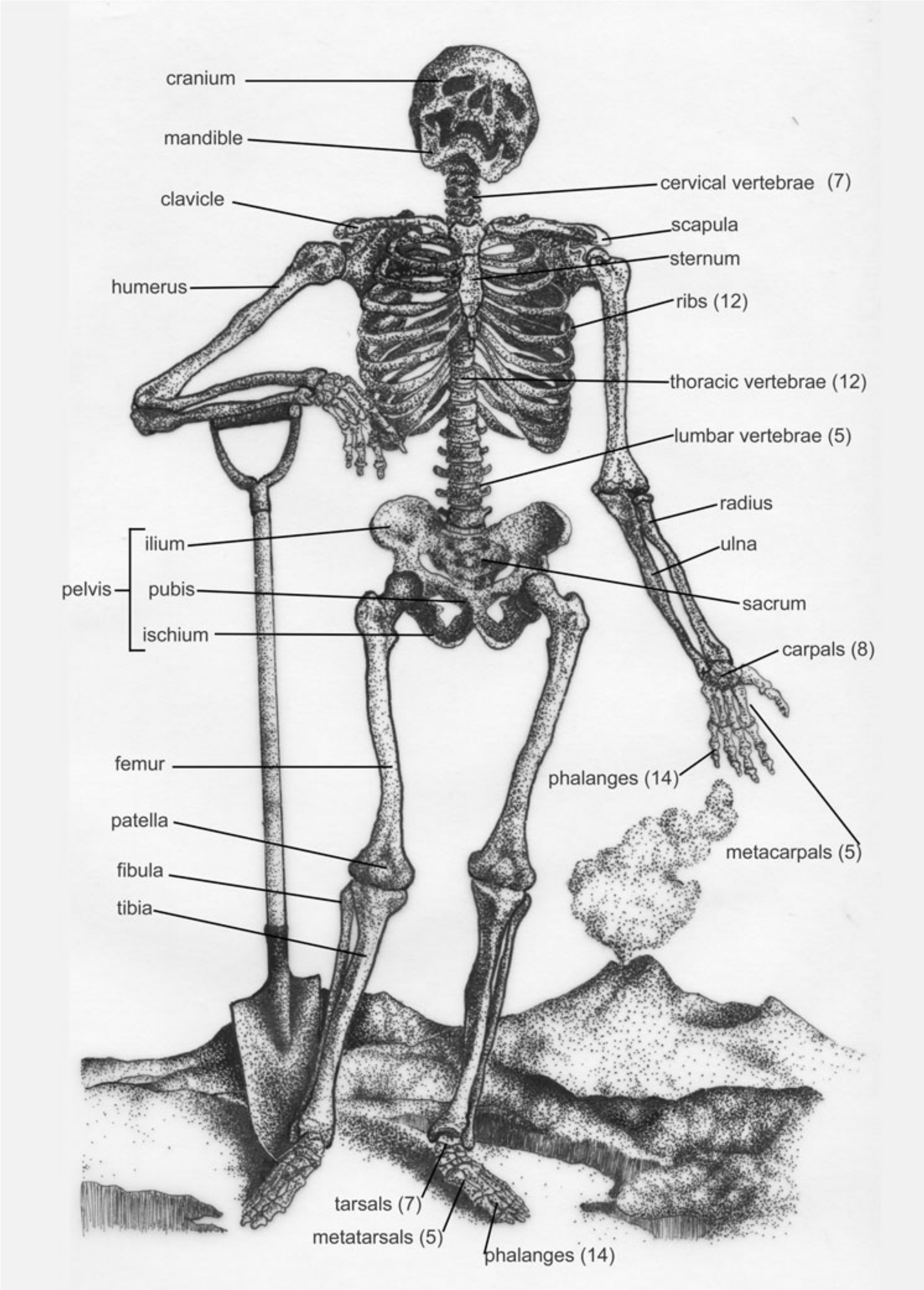

Fig. 24. Drawing by Estelle Lazer adapted from Lazer (2009), *Resurrecting Pompeii*: 295 (figure A3.5 Skeleton, with apologies to Vesalius (adapted from Vesalius' first book of *De Humani Corporis Fabrica*, *c*.1543. Reproduced in Saunders and O'Malley, 1982, 85)).

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DNA or deoxyribonucleic acid A class of complex molecules called nucleic acids. DNA is found in the nucleus of virtually all living cells. It contains the genetic code that is required for a cell to produce the proteins needed to perform its function.
epiphysis A secondary centre of ossification of a long bone. It is separated from the shaft of a bone by cartilage, also known as the epiphyseal plate, which ossifies when growth has been completed.
facet A small, smooth area on a bone or tooth, which serves as a point of contact between bones or teeth. Tooth facets are often produced by wear.
femur Thigh bone.
fibula The outer, or lateral, lower leg bone.
fontanelle Areas of membrane between the ossification centres of infant cranial bones. It literally means a small spring or fountain.
fusion This is the term used to describe a union of two adjacent bones or parts of bone.
gracile From the Latin *gracilis*, which means slender.
growth Progressive changes in size and morphology during the development of an individual. Growth tends to be positively correlated with age.
head In an anatomical context, a head is a rounded smooth eminence that articulates with another bone.
incisor The first two front, or anterior, teeth on each side of the mandible and the maxilla.
lambda The midline point of intersection of the sagittal and lambdoid sutures.
mastoid process A large protuberance of the skull behind and below the external ear. This is the point of attachment for the sternomastoid muscle.
metric analysis Analysis based on measurements as compared to non-metric, which is based on observations rather than measurements.
non-metric observations made directly from bone where no measurement is involved.
skeletal age and skeletal maturation A measure of biological maturation, as compared to chronological age, and based on skeletal development. An age-at-death assessment can only produce a biological age, which may differ from the actual age the individual was when they died.
suture The fibrous joints between cranial bones. The word is derived from the Latin word *sutura* or seam.
synchondrosis The union of two bones by cartilage.
thoracic Relates to the chest. It is also used to describe the vertebrae that support the ribs in the thorax.
tibia The larger of the lower leg bones.
torus A bony prominence.
transverse process A process that extends laterally and dorsally from the arch of a vertebra. The term also applies to the lateral crest of a sacrum.
trepanation (or trephination) A surgical technique that involves making an artificial hole in the cranial vault of an individual. There are various different methods, including scraping away the bone with a sharp tool or drilling a series of holes.

trochanter The two processes that can be observed below the neck of the femur. These are the greater and lesser trochanter. An unusually prominent gluteal tuberosity on the femur shaft is generally referred to as a third trochanter.
ulna The medial lower arm bone.
vertebra A vertebra is a bone of the spinal column.
Wormian bones Extra-sutural bones. These additional bones can be observed in the suture line between the bones of the cranium.

Addresses for correspondence:
Dr Estelle Lazer
SoPHI A17, University of Sydney 2006 Australia
estelle.lazer@sydney.edu.au

Associate Professor Kathryn Welch
SoPHI A17, University of Sydney 2006 Australia
kathryn.welch@sydney.edu.au

Associate Professor Dzung Vu
dzungv@gmail.com

Assistant Clinical Professor Manh Vu
manhvu.vu@gmail.com

Dr Alain Middleton
alainm@ozemail.com.au

Roberto Canigliula
canigliula@gmail.com

Stijn Luyck
stijn.luyck@stl-international.be

Dr Giovanni Babino
giobabino@gmail.com

Prof. Massimo Osanna
massimo.osanna@beniculturali.it

REFERENCES

Calhoun, P.S., Kuszyk, B.S., Heath, D.G., Carley, J.C. and Fishman, E.K. (1999) Three-dimensional volume rendering of spiral CT data: theory and method. *Radiographics* 19: 745–64.
Capurso, A., D'Esposito, L., Masseroli, S.M. and Vanacore, S. (2015a) *Grande Progetto Pompei Intervento No. 34 Restauro di Reperti dei calchi di Pompei: Relazione Archeologiche, Tavola 2*. Pompei, Ministero dei Beni e delle Attività Culturali e del Turismo, Soprintendenza Speciale di Pompei, Ercolano e Stabia.
Capurso, A., D'Esposito, L., Masseroli, S.M. and Vanacore, S. (2015b) *Grande Progetto Pompei Intervento No. 34 Restauro di Reperti dei calchi di Pompei:Tavole-Schede Calchi, Tavola 3*. Pompei, Ministero dei Beni e delle Attività Culturali e del Turismo, Soprintendenza Speciale di Pompei, Ercolano e Stabia.

Cicchitti, A. (1993) *Pompei. Il primo calco trasparente (diario di uno scavo)*. L'Aquila, Il Nuovo.

Dalrymple, N.C., Prasad Srinivasa, R., Freckleton, M.W. and Chintapalli, K.N (1999) Introduction to the language of three-dimensional imaging with multidetector CT. *Radiographics* 25: 1409–28.

De Carolis, E. and Patricelli, G. (2018) *Impronte Pompeiane*. Rome, "L'Erma" di Bretschneider.

Dwyer, E. (2010) *Pompeii's Living Statues: Ancient Roman Lives Stolen from Death*. Ann Arbor, University of Michigan Press.

García y García, L. (2006) *Danni di guerra a Pompei: una dolorosa vicenda quasi dimenticata* (Studi della Soprintendenza Archeologica di Pompei 15). Rome, "L'Erma" di Bretschneider.

Gouraud, H. (1971) Continuous shading of curved surfaces. *IEEE Transactions on Comput*ers 20: 623–9.

Lazer, E. (1995) *Human Skeletal Remains in Pompeii*, 2 vols. University of Sydney, Ph.D. thesis.

Lazer, E. (1997) Pompeii AD 79: a population in flux? In S.E. Bon and R. Jones (eds), *Sequence and Space in Pompeii* (Oxbow Monograph 77): 102–20. Oxford, Oxbow Books.

Lazer, E. (2007) Victims of the cataclysm. In J.J. Dobbins and P.W. Foss (eds), *The World of Pompeii*: 607–19. London, Routledge.

Lazer, E. (2009) *Resurrecting Pompeii*. London, Routledge.

Lazer, E. (2016) Skeletal remains and the health of the population at Pompeii. In M. Flohr and A. Wilson (eds), *The Economy of Pompeii*: 135–59. Oxford, Oxford University Press.

Maiuri, A. (1961) Last moments of the Pompeians. *National Geographic* 120: 651–69.

Meyer, D.H. and Fives-Taylor, P.M. (1998) Oral pathogens: from dental plaque to cardiac disease. *Current Opinion in Microbiology* 1: 88–95.

Molloy, J., Wolff, L.F., Lopez-Guzman, A. and Hodges, J.S. (2004) The association of periodontal disease parameters with systemic medical conditions and tobacco use. *Journal of Clinical Periodontology* 31: 625–32.

O'Reilly, P.G. and Claffey, N.M. (2000) A history of oral sepsis as a cause of disease. *Periodontology* 23: 13–18.

Osanna, M. (2019) *Pompei. Il tempo ritrovato: le nuove scoperte*. Milan, Rizzoli.

Perandini, S., Faccioli, N., Zaccarella, A., Re, T. and Mucelli, R.P. (2010) The diagnostic contribution of CT volumetric rendering techniques in routine practice. *Indian Journal of Radiology and Imaging* 20: 92–7.

Rocco, T. (2003) The House of the Golden Bracelet (VI, 17. 42). In P.G. Guzzo (ed.), *Tales from an Eruption: Pompeii, Herculaneum, Oplontis: Guide to the Exhibition*: 153–62. Milan, Electa.

Saunders, J.B.d.C.M. and O'Malley, C.D. (1982) *The Anatomical Drawings of Andreas Vesalius*. New York, Bonanza Books.

Shreiber, R. (n.d.) 3-D reconstruction in radiology. www.carestream.com/3dRecon_whitePaper.pdf (accessed 20 July 2017).

Ubelaker, D.H. (1989) *Human Skeletal Remains: Excavation, Analysis, Interpretation* (second edition) (Manuals on Archaeology 2). Washington, DC, Taraxacum.

White, T.D., Black, M.T. and Folkens, P.A. (2012) *Human Osteology* (third edition). San Diego (CA), University of Berkeley Press.

Zompatori, M., Poletti, V., Rimondi, M.R., Battaglia, M., Carvelli, P. and Maraldi, F. (1997) Imaging of small airways disease, with emphasis on high resolution computed tomography. *Monaldi Archives for Chest Disease* 52: 242–8.