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Virtual anthropology and forensic arts: the facial reconstruction of Ferrante Gonzaga

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A B S T R A C T

In the last few years virtual anthropology has been used to solve different problems that could not be properly addressed using a traditional anthropological approach. Mainly when dealing with mummies or embalmed bodies, the virtual approach is the only solution to carry out a detailed analysis of the skeleton without jeopardizing the integrity of the physical remains.

Based on these new technologies, the embalmed body of Ferrante Gonzaga (1507–1557), an Italian noblemen of the Renaissance period, was CT scanned and the digital three-dimensional data were used for virtual anthropological analysis. A physical model of the skull was obtained by rapid prototyping technique and used for facial reconstruction according to forensic art methods. Finally, the reconstructed face was compared with two portraits of Ferrante Gonzaga (Uffizi and Ambras portraits) using a virtual skull-painting superimposition technique. Despite the limits of the superimposition method when dealing with historical portraits in fronto-lateral view, our results pointed out more similarities with the Ambras portrait. By means of this multi-disciplinary approach, doubts regarding the reliability of historical portraits could be resolved.

1. Introduction

Virtual anthropology (VA) is becoming a fundamental tool for anthropological analysis. VA allows researchers to deal with problems that could not be resolved using traditional anthropological approaches without compromising the integrity of the physical remains (i.e., analysis of mummies, reconstruction of deformed fossils, etc.). Three-dimensional (3D) digital models of the physical object allow for virtual manipulation, simulation, and bone sectioning, etc., in a virtual space, therefore preserving the original object from invasive procedures. Furthermore, the development of sophisticated software and hardware contributes not only to an increase in the amount of data available for scientific analysis, but also improves the quality and objectiveness of the research.

The combination of these two aspects makes VA the perfect tool in bioarcheology for studying mummies and embalmed individuals. Until the late 1970s, mummies were investigated by means of two-dimensional (2D) radiographic images as was done by the pioneering work of Konig (1896). Nonetheless, in using only this approach it is difficult to understand the precise anatomy or morphology of an area under examination. 3D imaging techniques such as computer tomography (CT) and magnetic resonance imaging (MRI) overcome these limits. They allow us to visualize almost every anatomical and pathological structure with a high resolution and quality.

By mean of these technologies, the embalmed body of Ferrante Gonzaga (1507–1557) was analyzed.

Ferrante is the third son of Francesco II Gonzaga, Marquis of Mantua, and Isabella d'Este. He was the brother of Federico II, who became Duke of Mantua (1530) and Marquis of Monferrato (1533–1536), and of the Cardinal Ercole Gonzaga, who was appointed president of the Council of Trent (1562–1563). Ferrante was invited to the Spanish Court on the Emperor Carlo V's service

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and received the prestigious honour of the Golden Fleece (a knightly order instituted in 1430 by Philip the Good, duke of Burgundy). Thanks to his merits, Ferrante was nominated Viceroy of Sicily (1535–1546) and subsequently was appointed Governor of Milan (1546–1554). He died in Bruxelles on November 16th 1557, due to a fall from a horse and battle fatigue received at the Battle of St. Quentin. In order to have the body preserved for burial closer to home, an embalming treatment was performed to prevent decomposition during the long trip from Bruxelles to Mantua. This treatment involved removal of the brain, removal of the organs and subsequent packing of the body cavity with aromatic herbs. Afterwards, the body was wrapped in a linen shroud and laid into a lead coffin surrounded further by a wooden coffin. Ferrante was initially buried in the sanctuary of Madonna delle Grazie di Curtatone (Mantua), but the embalmed body was later moved to the sacristy of the Mantua's Cathedral. The coffin was placed on a lateral wall of the sacristy near the grave of the brother Cardinal Ercole, at about 10 m high, held by marble supports.

Ferrante Gonzaga was described as noblemen and was well respected in political affairs. Based on the physical description furnished by his biographer Gosellini (1579), Ferrante is depicted as handsome man, with above average stature and with a well proportioned body. The seriousness of his appearance is conveyed through his large black eyes, thick beard and general demeanour. Ferrante's persona was respected among the general population, so that just his appearance was sometimes enough to placate tumults generated by riotous soldiers (Gosellini, 1579). This is a positive picture of Ferrante, nonetheless we should always remain aware of the potential for bias in such biographical descriptions. Therefore, on one side the biographic information has to be carefully evaluated for a preliminary understanding of the personage, yet on the other side further physical biological information can only be obtained by an anthropological analysis of the embalmed body.

The year 2007 marked the quincentenary of his birth. This celebration was the perfect occasion to organize cultural events and to carry out the recognition of the Ferrante's body (Fig. 1). Virtual anthropology, forensic arts and physical anthropology were employed for the anthropological analysis of the skeletal remains and finally for the positive identification of Ferrante Gonzaga. Because it was not possible to directly analyze the skeleton, or to create a cast of Ferrante's skull, the embalmed body was CT scanned. Virtual anthropometry was carried out on 3D digital models of the long bones. The skull was virtually restored and a physical copy was created by rapid prototyping techniques (RPT). Accordingly, two forensic approaches were employed for the identification of the individual: facial reconstruction based on forensic art techniques (Prag and Neave, 1997; Taylor, 2001; Wilkinson, 2004; Quatrehomme et al., 2007); and skull/painting superimposition, which is a modified version of the well known skull/photo superimposition (i.e., Yoshino et al., 1997; Solla and Işcan, 2001; Fenton et al., 2008).

Fig. 1. The embalmed body of Ferrante Gonzaga.

Both of these approaches have previously been used in bioarcheology. For example, several researchers have applied facial reconstruction in the archaeological field to recreate the look of historic figures (i.e., Wilkinson and Neave, 2003; Benazzi et al., 2009a) and mummies (Neave, 1979; Cesarani et al., 2004; Gill-Robinson et al., 2006). At the same time, skull/painting superimposition has been used in the past (Frassetto, 1933; Pearson and Morant, 1934) and recently applied by Benazzi et al. (2009b) for the identification of Angelo Poliziano, in which the authors emphasized the challenge of this approach when portraits (like those dated by XVth–XVIth centuries) depict the face in fronto-lateral view.

2. Material and methods

The coffin housing the body of Ferrante Gonzaga was opened during a survey carried out in 2007. The CT scan was performed at the radiology department of Carlo Poma Hospital (Mantova) by means of Somatom Sensation 16-Slice CT Scanner (Siemens Medical Solutions USA, Inc. Item) with a slice thickness of 0.75 mm 3D digital models of the skeletal segments were built using Amira 4.1 software (©Mercury Computer Systems, Chelmsford, MA). The models were achieved semi-automatically by threshold-based segmentation, contour extraction and surface reconstruction. As a result, the wrapped tissue (Fig. 2a) was virtually removed (Fig. 2b) allowing the skeleton to be visualized and analyzed. Post-processing procedures were required in order to clean and patch the 3D models.

2.1. Virtual anthropometry of the post-cranial bones

3D models of the long bones were imported into Rhino 3.0 (Robert McNeel and Associates, Seattle, WA) and virtual anthropometric measurements were carried out following the indication provided by Martin and Saller (1956–1959) (Fig. 3). The measurements were used in order to obtain indices useful for anthropological descriptions of Ferrante.

Ferrante Gonzaga's stature was assessed from the femoral and tibial physiological lengths via the formula of Pearson (1899) and Trotter and Gleser (1952). As those formulae were determined in populations which Ferrante Gonzaga did not belong to, the following estimations must be considered cautiously.

2.2. Virtual restoration of the skull

Embalming procedures for removing the brain were clearly visible in the cranial vault. In fact, a sub-square perforation involved both the parietal bones, crossing the midsagittal plane. The perforation was obviously executed by means of a sharp knife, completely penetrating the skull. The cut marks were clearly visible

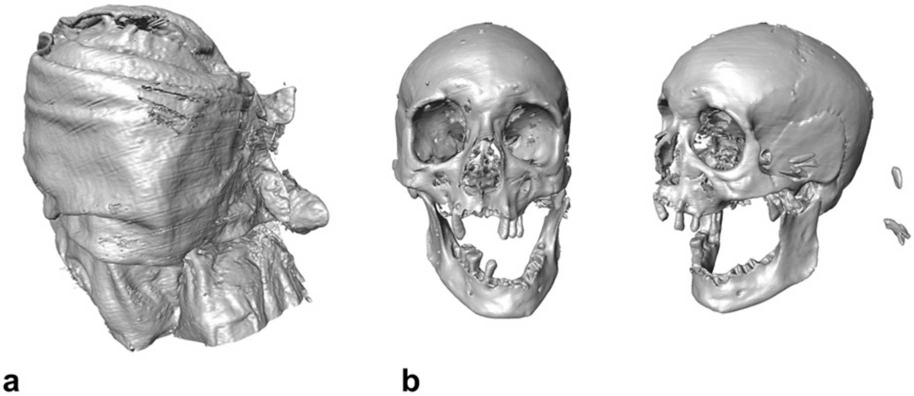

Fig. 2. a) 3D digital model of the Ferrante's skull wrapped in linen tissue; b) frontal and fronto-lateral view of the unwrapped skull: teeth are visible near the left zygomatic arc and beside the left vault of the cranium.

in the corners of the hole, while the removed parietal portion was found inside the endocranium (Fig. 4a).

Therefore, in RapidForm XOR2 (INUS Technology, Inc.) the parietal portion was virtually displaced in the proper position. Due to the pressure applied by the wrapped tissue and maybe to some taphonomic events, the mandible was disarticulated, displaced towards the left side of the cranium with the left condyle fractured (Fig. 4b). For the same reasons, and perhaps also due to pathological events that contributed to reduce the height of the alveolar process (i.e., periodontite), most of the teeth were freed from the alveolar sockets. Most of the teeth were found between the left zygomatic arch and the temporal fossa, as well as in the basicranium (Fig. 2b). Accordingly, all the scattered teeth, as well as the teeth still remaining in the sockets but with anomalous position (i.e., the upper right canine), were virtually removed. Due to the partially damaged upper and lower alveolar process and the general shallow conditions of the sockets (maxillary and mandibular), the scattered teeth were not repositioned in anatomical position.

The left condyle of the mandible was reconstructed using thin plate spline (TPS) interpolation functions following the procedures outlined by Benazzi et al. (2009c). A template made by three anatomical landmarks and 121 semilandmarks was created on the mirrored copy of the right hemimandible (reference model) in Viewbox software (dHAL Software, Kifissia, Greece). Three curves that followed margins of anatomical structures on the hemimandible were marked, and 38 semilandmarks were selected along these curves. Moreover, a further 83 semilandmarks were digitized on the surface of the 3D model (Table 1, Fig. 5a).

The same template was digitized on the original left hemimandible (target model). Although the landmarks are homologues between the reference and the target model, the semilandmarks need to slide in order to achieve geometric homology by means of relaxing semilandmarks on the target against the reference model.

The relaxation procedure is based on the application of the TPS function, which optimizes location of semilandmarks so that the bending energy (calculated as the bending energy of an infinitely thin metal sheet) is minimized for the shape (Bookstein, 1997; Gunz et al., 2005, 2009). The semilandmarks were allowed to slide along tangents to the curves or tangent planes to the surface at the respective point of the location of the semilandmarks (Bookstein, 1997). In the course of the sliding, missing semilandmarks (relative to the condyle portion) were allowed to move without constraints (they were not restricted in curves or onto the surface) so that the bending energy of the overall deformation was minimized (Fig. 5b). For a more detailed discussion about condyle reconstruction, see Benazzi et al. (2009c).

In Amira, the surface of the reference hemimandible was then warped onto the landmarks and semilandmarks defined on the target model with the help of the Bookstein transformation mode based on the TPS interpolation (Bookstein, 1997). All of the 124 landmarks and semilandmarks of the reference model were thus transformed into the corresponding landmarks and semilandmarks of the target model. The surface of the reference model was automatically warped so as to minimize the bending energy of the corresponding transformation with the nearest neighbouring interpolation used for resampling the final model. The result of this warping procedure is a new digital model from which the reconstructed condyle was virtually isolated and merged to the original mandible (Fig. 5c).

Finally, the digital models of both the cranium and the mandible (Fig. 6a) were constructed using a rapid prototyping system (Fig. 6b). The two physical models were generated by Stratasys Dimension SST (*Soluble Support Technology*), a system based on FDM (*Fused Modelling Deposition*) technology (Gatto and Iuliano, 1998). This method allows for the creation of prototypes

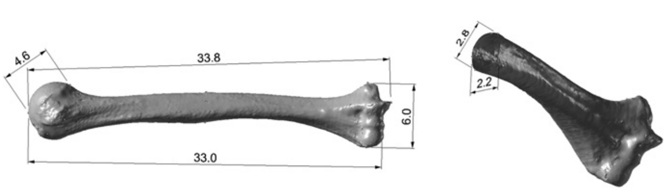

Fig. 3. Virtual anthropometry of the right humerus. On the right, the humerus was sectioned in order to visualize the diameters at the mid-diaphysis.

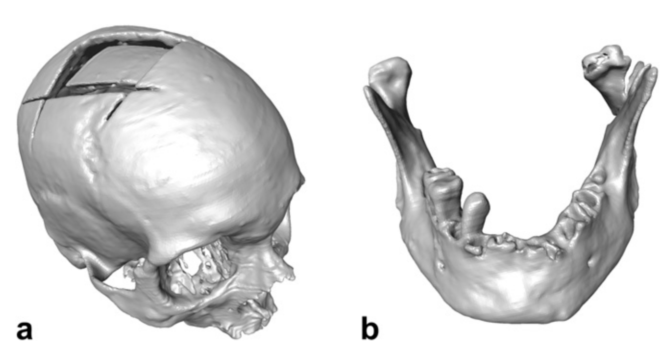

Fig. 4. a) The cranium of Ferrante Gonzaga; the cranial perforation and the parietal fragment are well recognized; b) the mandible of Ferrante with the damaged left condyle.

Table 1
List of landmarks and curves identified on the 3D digital models of the hemimandibles.

N	Landmark name	*N*	Curve name	Smlm count[a]
1	Infradentale (I)	1	Lower mandible (Lm)	20
2	Coronoid process (C)	2	Ramus anterior ridge (R)	10
3	Lingula (L)	3	Sigmoid notch (S)	8
			Total semilandmarks on curves	38

[a] semilandmarks identified on the curves

by the addition of subsequent layers of ABS (Acrylonitrile Butadiene Styrene) plastic material with 0.254 mm thickness. The sparse fill option, which creates an interior honeycomb structure, was chosen to save time and material and to produce lighter models. The resulting physical model of the skull (Fig. 6b) was then used as the basis for the next step of the facial reconstruction technique.

2.3. Facial reconstruction

Despite the improvement of the automatic-computer based procedures for cranial reconstruction, more extensive quantitative validation of the outcomes are still required (Vandermeulen et al., 2006). At the same time, because computer-aided facial reconstruction requires sophisticated techniques that are controlled by few teams in the world unfortunately, manual methods continue to be used by more forensic scientists (Quatrehomme et al., 2007). Accordingly, manual facial reconstruction was carried out on an epoxy cast of the prototyped Ferrante's skull according to the Manchester protocol method (Prag and Neave, 1997; Wilkinson, 2004). Pegs representing tissue depth markers were glued in 34 paired and unpaired craniometric points of the skull. The pegs were pre-cut to the required length as described by the reference standards (Wilkinson, 2004), according to the muscle development, sex and age of the individual (50 years old). The skull was then positioned in the Frankfurt plane and the muscles of the face were individually modelled using plasticine. The robusticity and development of the muscles, mainly the muscles involved in facial expression, were inferred by thorough observation of the muscle attachments on the maxilla, the inferior borders of the orbits, the zygomatic bones, the zygomatic arches and the temporal line (Fig. 7a). Subsequently, the model was coated with plasticine up to the peg's tip, and the skin was modelled so that the face was consistent with a 50 year old man (Fig. 7b). Next, the eyes, nose, ears and mouth were added and refined. Particular care was taken

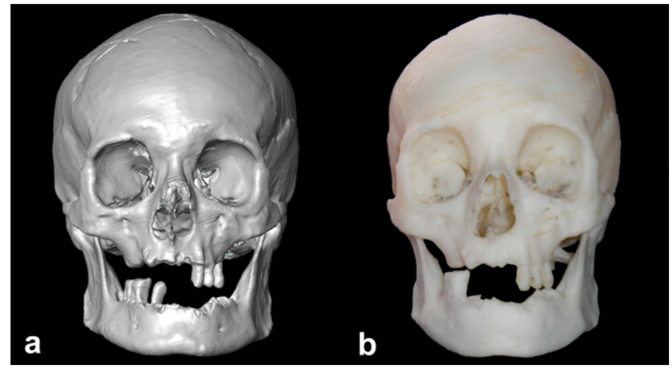

Fig. 6. a) 3D digital model of the skull: the mandible has been positioned in anatomical position; b) physical model of the skull made by RPT.

to ensure that the eyes were proportioned to the size of the orbital cavity and positioned in the middle of the orbits.

The shape of the nose was defined considering the prominent anterior nasal spine, the orientation of the nasal surface of the palatine bone and the straight direction of the nasal bones. The contour of the lips was calculated according to the indices proposed by Wilkinson (2004). While for forensic purposes realistic features in the final model should be avoided in order to prevent biased facial recognition (Cattaneo, 2007), in archaeology an attempt to represent what the person would have looked like in life is recommended. Therefore because in Ferrante's paintings and sculptures the beard is always present (Fig. 7c), the beard was included in the physiognomic reconstruction of the finished face.

2.4. Superimposition technique

The 3D digital model of the skull was superimposed onto two portraits of Ferrante in fronto-lateral view: 1) the portrait made by Cristofano Papi dell'Altissimo (Firenze, Galleria degli Uffizi); 2) and the portrait made by an Anonymous painter (Kunsthistorisches Museum, Schloss Ambras, Vienna).

In order to test the reliability of this procedure, the 3D model was previously superimposed to a fronto-lateral view of the reconstructed face. As suggested by Benazzi et al. (2009b) the pictures and the digital model of the skull were imported in Amira, and the orthogonal view was set. By means of dynamic translation, rotation and uniform scaling process, the skull was aligned either to the reconstructed face or to the portraits using virtual tissue depth markers (virtual pegs) defined on the digital skull to aid the process

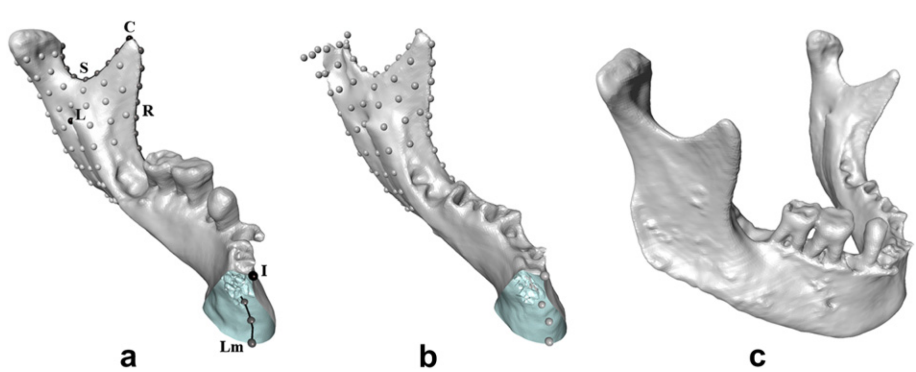

Fig. 5. a) Landmarks and semilandmarks identified on the template (mirrored copy of the right hemimandible); b) set of landmarks and semilandmarks identified on the target model (left hemimandible); c) mandible with the reconstructed left condyle.

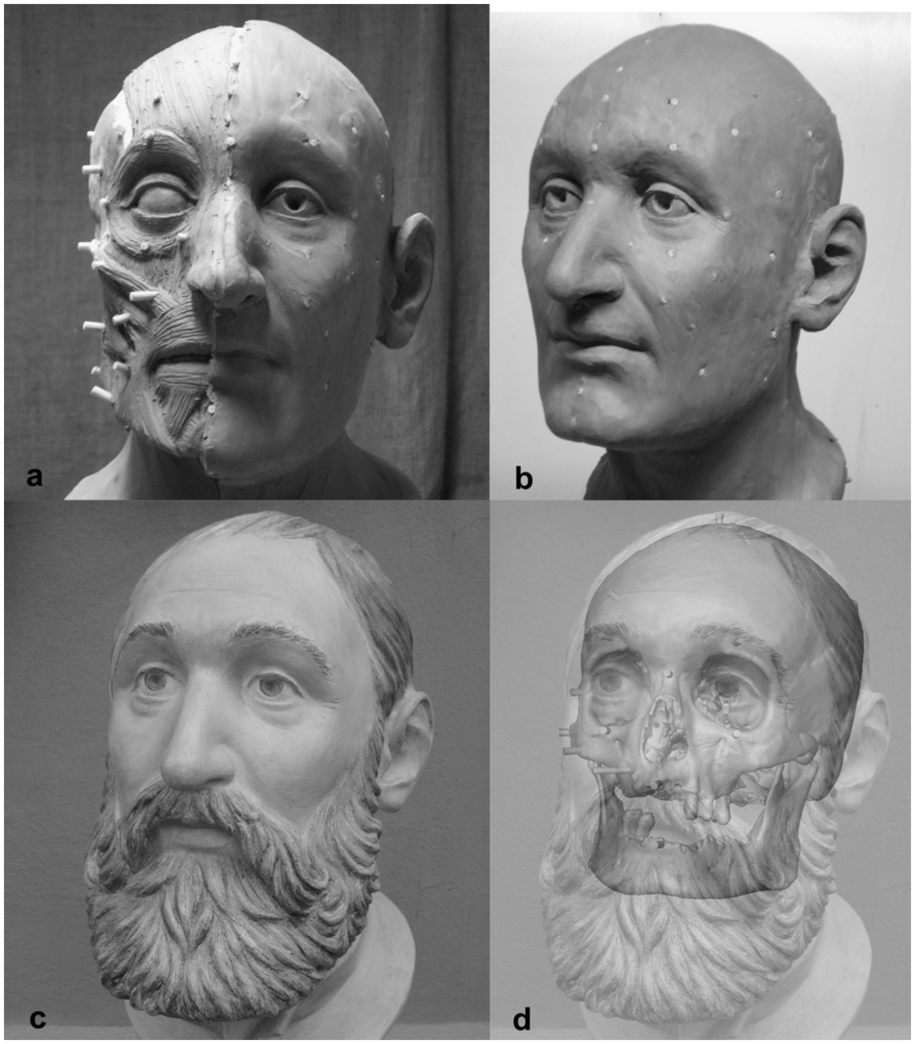

Fig. 7. Cranio-facial reconstruction of Ferrante; a) pegs and plasticine modelled to recreate the muscles; b) skin modelled as representing a 50 year old man; c) final reconstruction of Ferrante's face; d) skull-photo superimposition of the 3D digital model of the skull with the reconstructed face.

of skull orientation and sizing. More detailed information about this procedure are provided by Benazzi et al. (2009b).

3. Results

3.1. Anthropometry

In general, the robustness index of the long bones falls inside the mean values, without remarkable difference between left and right side. The only exception concerns the high robustness index of both humeri ($R = 22.2$; $L = 21.0$), probably related to the more intense functional use of the arms compared with the lower limbs. Section index of the shaft of the humerus indicates eurybrachy ($R = 78.6$; $L = 83.1$), underlining a round shape of the diaphysis, with associated euroleny of the ulne ($R = 89.3$; $L = 86.4$). The shafts of the femurs are not antero-posterior flattened, as pointed out by the larger value of the platymeric index ($R = 96.1$; $L = 97.6$); at the same time, both femurs have a high pilastric index values due to the marked linea aspera ($R = 118.8$; $L = 120.3$). The mean cross-section index at the nutrient foramen of tibia indicates eurycnemy ($R = 77.4$; $L = 75.2$) rather than lateral flattening. Finally, the estimated stature of Ferrante Gonzaga was about 167 $\pm$ 2 cm (Pearson, 1899) and 170 $\pm$ 3 cm (Trotter and Gleser, 1952).

3.2. Skull/painting superimposition

In Fig. 7d is displayed the superimposition of the skull to the reconstructed face. The skull follows the facial outline, delimited upward by the peg of the vertex and downward by the peg related to the lower lip. The inclination of the frontal bone follows the orientation of the forehead. The virtual pegs of the left and right midsupraorbital regions are positioned at the level of the eyebrow, and both external orbital borders are well marked by the tip of the lateral orbital pegs. Finally, the tip of the right zygomaxillary peg marks the external limit of the soft tissue of the right zygoma.

Since in the Uffizi portrait (Fig. 8a) only the face is depicted, the virtual orientation of the skull was assessed without considering the backward extension of the head. The position of the skull was mainly defined by the orbital pegs, the nasal aperture and the zygomatic breadth (Fig. 8b). Both midsupraorbital pegs are located along the eyebrows, while the later orbital pegs mark properly the later border of the orbit. The nasal aperture falls perfectly behind the nose, and the zygomatic bone follows the profile of the zygoma, even if the zygomaxillary peg falls outside of it. An additional left shift of the skull was not possible because the right eye is already positioned close to the lateral orbit rim. The superimposition fails in the frontal region, because the forehead of the portrait is higher and

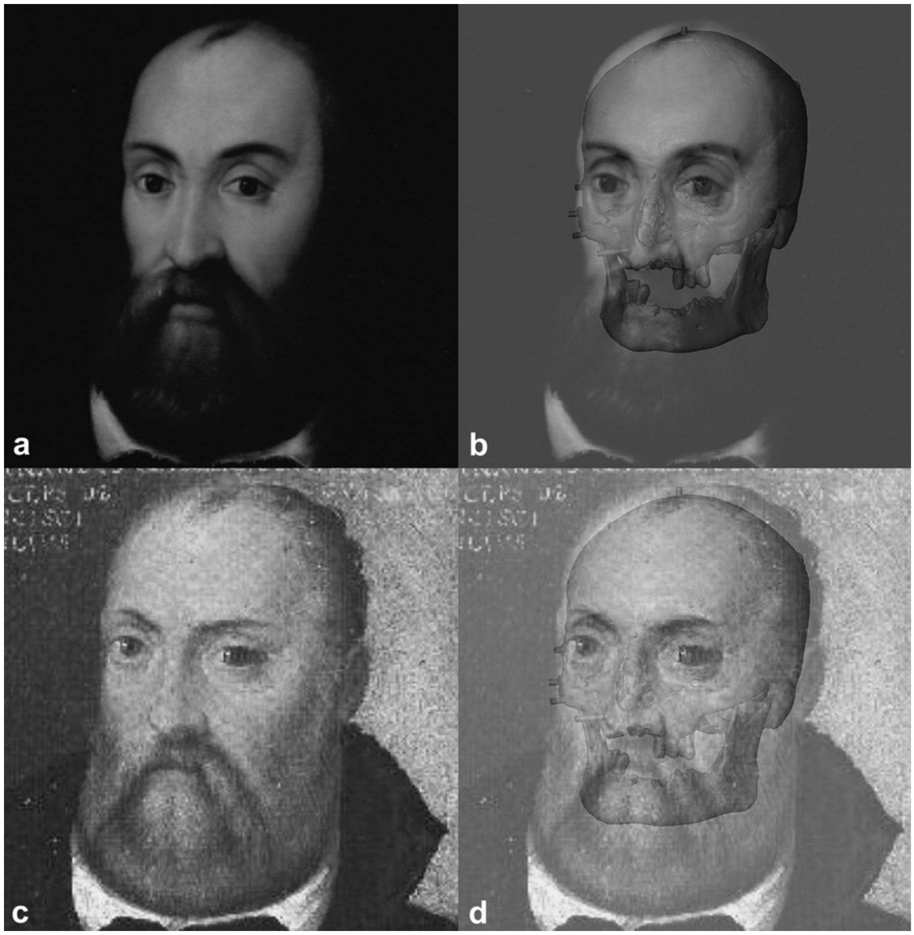

Fig. 8. a) Portait of Cristofano Papi dell'Altissimo, *Ritratto di Ferrante Gonzaga*, Firenze, Galleria degli Uffizi (Uffizi portrait); b) skull-painting superimposition of the 3D digital model of the skull with the Uffizi portrait; c) Anonymous painter, *Ritratto di Ferrante Gonzaga*, Wien, Kunsthistorisches Museum, Schloss Ambras (Ambras portrait); d) skull-painting superimposition of the 3D digital model of the skull with the Ambras portrait.

orthogonal than the frontal bone of the skull. An additional increase in size of the skull would have further compromised the final outcome (Fig. 8b).

Better results were obtained with the second portrait (Ambras portrait, Fig. 8c). The skull was oriented based on features identified on the face of the portrait and in relation to the backward extension of the head. The upper and lower position of the facial bones is defined by the pegs at the vertex and at the lower lip respectively. The forehead is slightly less orthogonal than in the former portrait, and it is more consistent with the frontal bone of the skull. Ferrante's left eye is inside the orbital cavity, while the right one is shifted towards the right lateral orbital rim. Nevertheless, this mismatch could be due to a mistake of the painter or it may reflect a specific intention of the artist in drawing the right eye. The nasal aperture is correctly behind the nose, and the zygomatic bone follows the profile of the zygoma. As seen before for the Uffizi portrait, in the second painting the zygomaxillary pegs goes outside the border of the soft tissue (Fig. 8d).

4. Conclusions

The embalmed body of Ferrante Gonzaga provided the opportunity to combine VA and forensic arts for digital skeletal analysis and facial reconstruction for identification purposes. By means of the virtual approach, information concerning the skeletal tissue was available for anthropologists without compromising the integrity of the physical remains.

With a stature of about 167 cm (or 170 cm using Trotter and Gleser (1952) formula), Ferrante was in the mean value of stature estimated by Giannecchini and Moggi-Cecchi (2008) for the Medieval period (166.9 $\pm$ 4.3 cm) using Pearson (1899) formula. This result deviates from the statements of Gosellini (1579), for which Ferrante largely exceeded the mean value. The large robustness index of the upper limbs could be surely related to his activities.

Because forensic arts has to deal with many ambiguous variables (such as the shape of the eyes, the lips and the nose), cranio-facial reconstruction cannot claim to provide with absolute certainty the look of the personage. On the other hand, we can assume that facial reconstruction based on forensic procedures is the most scientific approach to obtain an approximated aspect of the face, at least regarding the overall shape. The reconstruction showed clear similarity with the two Ferrante's portraits, at least for the thick and elongated shape of the face and the pronounced cheek bone (well marked in the second portrait). Nevertheless, some differences were also recognized. The orthognathic forehead of the portraits, that is more emphasized by Cristofano Papi dell'Altissimo (Fig. 8a), contrasts with the evident backward inclination of the frontal bone (Fig. 6a), which is consequently reflected in the less orthognathic forehead of the reconstructed face (Fig. 7b,c). This mismatch was underlined by digital skull-painting superimposition technique, which also emphasized the better match (even if not perfect) between the skull and the Ambras portrait (Fig. 8d). It is important to stress that the superimposition required different adjustments of the skull in order to obtain a proper size and position of the skull in relation to the fronto-lateral view of the portrait. The technical difficulty of this approach and the reliability of the result was verified using a fronto-lateral picture of the reconstructed face. Despite the optimized condition of the test (we are certain about the correspondence between the skull and the face), the superimposition process was a challenge. For this reason, when dealing with fronto-lateral view of historical portraits, the results obtained from the skull-painting superimposition technique cannot be used for a clear positive identification, but rather to highlight which is the best correspondence between skull and portrait. Based on these assumptions, the superimposition held more similarities with the Ambras portrait.

This result is consistent with information obtained by the historical documentations. In fact, the Ambras portrait is presumably based on a previous painting by Fermo Ghisoni for the sanctuary of Madonna delle Grazie (Mantua), in which Ferrante is depicted with his wife Isabella di Capua (Bertelli, 2007). Since Ghisoni met Ferrante, the physiognomic characteristic depicted on the painting, as well as all the subsequent portraits based on that (e.g., the Ambras portrait), could be considered reliable. Different events characterized the portrait made by Cristofano Papi dell'Altissimo. In order to realize portraits of famous historical personages for the Uffizi gallery (Florence), in 1552 Cristofano Papi went to the villa of Paolo Giovio (Como, Northern Italy) in which were housed several portraits. Nonetheless, based on historical documents, it is highly probable that Giovio did not have a portrait of Ferrante (L'Occaso, 2007). Therefore, the source of the portrait by Cristofano Papi is not clear. This portrait belongs to a second series of Ferrante's portraits that are slightly different from the group in which the Ambras portrait is included.

As emphasized by the results, the multi-disciplinary integration of different techniques and knowledge (VA, technical-modelling, forensic anthropology, history and art), provided not only the opportunity to analyze the embalmed body of Ferrante Gonzaga in a non-invasive way, but also to shed light on some unsolved issues regarding the ambiguity among several Ferrante's portraits.

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