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Complete List of Authors:	Minozzi, Simona; Universita degli Studi di Pisa, Department of Translational Research and Advanced Technologies in Medicine and Surgery Panetta, Daniele; Istituto di Fisiologia Clinica CNR De Sanctis, Massimo; Universita degli Studi di Pisa Dipartimento di Ingegneria Civile e Industriale Giuffra, Valentina; Univerisità di Pisa, Department of Translational Research and Advanced Technologies in Medicine and Surgery
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Abstract:	Background During archaeological excavation, carried out in the S. Francesco Monastery at Lucca (Tuscany, Italy), a golden dental appliance was discovered. The prosthesis was found, together with commingled human remains, in the collective tomb of the aristocratic family of the Guinigi, a powerful family who governed Lucca from 1392 until 1429. The exact archaeological dating of the prosthesis was not possible, but some elements suggest a dating to the beginning of the 17th century. Purpose Aim of the paper is to study and describe the dental appliance trough a multidisciplinary approach. Materials and Methods Macroscopical and micro-CT examination were performed to investigate the technics used for the realization of the dental prosthesis. SEM analysis was performed to study alloy composition of the metallic fixing lamina and microstructure of the deposits on the dental surface. Results The dental prosthesis consists in five mandibular teeth: three central incisors and two lateral canines linked together by a golden band inserted into the dental roots to replace the anterior arch of the jaw. Micro-CT scan revealed the presence of two small golden pins inserted into each tooth crossing the root and fixing the teeth to the internal gold-band. SEM examination of the lamina indicated a homogeneous composition, with average contents of 73 wt% gold, 15.6 wt% Ag and 11.4 wt% Cu. Apposition of dental calculus on the teeth indicated that the prosthesis had been worn for a long period. Conclusions This dental prosthesis provides a unique finding of technologically

	advanced dentistry in this period. In fact, during the Early Modern Age some authors described gold band technology for the replacement of missing teeth; nevertheless, no direct evidences of these devices have been brought to light up so far.

A Dental Prosthesis from the Early Modern Age in Tuscany (Italy)

Dr. Simona Minozzi PhD*

Dr. Daniele Panetta **

Prof. Massimo De Sanctis PhD***

Prof. Valentina Giuffra PhD*

*Division of Paleopathology, Department of Translational Research and Advanced Technologies in Medicine and Surgery, University of Pisa, Italy.

** CNR, Institute of Clinical Physiology (IFC-CNR), Pisa, Italy

*** Department of Civil and Industrial Engineering, University of Pisa, Pisa, Italy

Corresponding author: Simona Minozzi, Divisione di Paleopatologia, Università di Pisa, via Roma 57 Pisa 56126. Tel/fax: +39 050 992894 – email: simo.min@tiscali.it

Author contributors

S. Minozzi recovered and studied the dental prosthesis, and wrote the manuscript; D. Panetta carried out micro-CT examination furnishing help for interpretation of the data, M. De Sanctis performed SEM analysis and wrote the relative part of the manuscript; V. Giuffra completed the manuscript studying the historical background and literary sources.

All the authors have no conflict of interest relevant to the content of the paper

Abstract

Background

During archaeological excavation, carried out in the S. Francesco Monastery at Lucca (Tuscany, Italy), a golden dental appliance was discovered. The prosthesis was found, together with commingled human remains, in the collective tomb of the aristocratic family of the Guinigi, a powerful family who governed Lucca from 1392 until 1429. The exact archaeological dating of the prosthesis was not possible, but some elements suggest a dating to the beginning of the 17th century.

Purpose

Aim of the paper is to study and describe the dental appliance trough a multidisciplinary approach.

Materials and Methods

Macroscopical and micro-CT examination were performed to investigate the technics used for the realization of the dental prosthesis. SEM analysis was performed to study alloy composition of the metallic fixing lamina and microstructure of the deposits on the dental surface.

Results

The dental prosthesis consists in five mandibular teeth: three central incisors and two lateral canines linked together by a golden band inserted into the dental roots to replace the anterior arch of the jaw. Micro-CT scan revealed the presence of two small golden pins inserted into each tooth crossing the root and fixing the teeth to the internal gold-band. SEM examination of the lamina indicated a homogeneous composition, with average contents of 73 wt% gold, 15.6 wt% Ag and 11.4 wt% Cu. Apposition of dental calculus on the teeth indicated that the prosthesis had been worn for a long period.

Conclusions

This dental prosthesis provides a unique finding of technologically advanced dentistry in this period. In fact, during the Early Modern Age some authors described gold band technology for the replacement of missing teeth; nevertheless, no direct evidences of these devices have been brought to light up so far.

Introduction

Archaeological investigations carried out in the S. Francesco Monastery at Lucca (Tuscany) in 2010, unearthed the burials of the aristocratic members of the Guinigi, a powerful family of traders and bankers, who in 1392 took the power and governed the city until 1429.

In 1358 Francesco di Bartolomeo Guinigi, uncle of the more famous Paolo Guinigi, commissioned the construction of the Guinigi Chapel near the cloister of the convent of S. Francesco, which was used as a private funerary chapel between the end of the 14th and the first half of the 17th century.

The bodies of the Guinigi were buried together in two large stone tombs, in which the skeletal remains of successive inhumations were accumulated over the years. The most part of the skeletons underwent relocations and lost the anatomic connection, so that it was impossible to provide single individual reconstructions.

During the archaeological excavations, a golden dental appliance was discovered together with the commingled bones of the Guinigi, providing a unique finding of technologically advanced dentistry in this period. In fact, during the Early Modern Age some authors described gold band technology for the replacement of missing teeth; nevertheless, no direct evidences of these devices have been brought to light up so far.

Materials and Methods

The prosthesis was found with commingled human remains in the lower stratigraphic layer (US1278) of one of the two collective tombs named “Cassone Sud”, and may be dated back to the early years of utilization of the tomb, at the end of 14th century. The exact archaeological dating of the prosthesis was not possible because some alterations occurred over the centuries, as the device might have slid down from the upper layers. In fact, some pottery fragments and devotional medals found in the same stratigraphic layer were dated to the beginning of the 17th century.

Macroscopical and microscopical examination of the prosthesis was performed to Stereomicroscope WILD 10-64 X magnification.

An IRIS micro-CT scanner (Inviscan Sas, Strasbourg France) allowed to investigate, non-destructively, the internal structure of the prosthesis[1]. A tomography acquisition was performed by

means of a high-resolution setup with the following settings: 80 kVp, 1 mA, 2000 projections over 360 degrees, with a total scan time of 102 s. Images were reconstructed using a cone-beam filtered backprojection algorithm (FBP), with an isotropic voxel size of 58.9 micron. The raw projection data was manually pre-filtered to attenuate the metal artifacts in the reconstructed images. Three-dimensional volume renderings (VR) were performed using VolView 3.4 (Kitware Inc, USA).

Preliminary studies were carried out to investigate the teeth surface deposits and on the alloy composition of the metallic fixing lamina by a ZEISS-EVO MA15 scanning electron microscope (SEM) equipped with an energy dispersive spectroscope (EDS) OXFORD INCA X-Act.

Description

The dental prosthesis consists of five teeth linked together by a golden band (Fig.1), which was realized using mandibular teeth to replace the anterior arch of the jaw. The teeth employed were three central incisors and two lateral canines, from right to left: right canine, left second incisor, two right central incisors, and left canine. Therefore, in this order, the correct anatomical sequence was not respected. Furthermore, the size and symmetry of the tooth shapes indicated that the teeth belonged to different individuals.

Macroscopical and micro-CT examination revealed the method used for the realization of the dental prosthesis. The appliance was 62 mm long. In each tooth, the root apex was removed by cutting and rubbing the root, as testified by small furrows and wear facets visible at stereo-microscope (Fig. 2). A longitudinal cut was made in mesio-distal direction along the root. The section was 7.6 mm long and 0.5 mm large, reaching the tooth neck. The teeth were then aligned and a subtle golden lamina, 3.5 mm large and 0.4 mm thick, was inserted into the fissure (Fig. 2).

Two small holes (0.8 mm large), one above the other, and therefore poorly adjusted, were made in each tooth, roughly in the middle of the root under the neck. The holes, barely visible macroscopically, were clearly revealed by micro-CT, in the same way as the small pins inserted into each hole, which crossed the root and fixed the teeth to the internal gold-band (Fig. 3). The pins departed from the lingual surface crossing the root and the golden plate, without perforating

the buccal surface of the root. The juxtaposition of the dental calculus on the lingual surfaces covered the holes (Fig.4), which could only be seen by CT-scan examination. The traces of the calculus indicate that the prosthesis had been worn for a long period.

The preparation of the replacement teeth also included modifications of the tooth crowns through abrasion of the lingual surface: in the right canine (first tooth on the right in lingual view) the most part of the lingual surface enamel was rubbed, uncovering the underlying dentine, as testified by parallel microstriations visible in 8x magnification. Similar wear facet and microwear pattern were observed in the tooth neck of the left canine (Fig. 4).

The gold-band had fallen out of the two lateral teeth of the prosthesis with S-shaped ends. In the extremity plate, two similar holes (0.8 mm diameter) intended to provide the anchor with the mandibular teeth still *in situ*, probably with strings. It was not possible to ascertain the anchor teeth, probably the first premolars, because any attempt to discover the mandible fitting with the prosthesis in the Cassone Sud tomb was unsuccessful.

SEM examination of the golden lamina was performed on the right S-shaped end (Fig. 5). All SEM images were obtained by using backscattered electrons (BSE) and, consequently, they also contain compositional information. This is because heavy atoms with high atomic number Z are more strongly scattered than the light ones and the resulting image contrast (different grey levels) is related to the average atomic number of surface atoms. In Figure 5A the presence of dark-coloured deposits (very rich of light atoms) is evident and is believed to be dental calculus. In fact, the relevant x-ray spectrum in Figure 5B evidences a massive presence of phospourus, calcium and oxygen, indicative of calcium phosphates, together with significant amounts of magnesium, aluminium, silicon, potassium, iron, and copper, which are usually present in the dental calculus. Abundant calculus deposits were also found on the tooth surfaces. By comparison, Figure 5C shows the x-ray spectrum from a calculus-free region on the golden lamina: the presence of whiter and darker regions could indicate significant differences in the local chemical compositions, since those regions are richer in heavier atoms, such as gold. As a matter of fact, the whiter regions show large amounts of gold, silver and copper typically below 6 wt%. On the contrary, darker regions were richer in less noble elements, with variable amounts of Ag-Cu, each element ranging

up to 10 wt%. The heterogeneous composition of the lamina surface could result from the partial dissolution of less noble Cu-Ag elements resulting from the corrosion processes over time. In order to verify this hypothesis, the S-shaped end of the lamina was slightly abraded by using SiC grinding paper Grit 1200, and repeating the EDS analysis on the polished surface. As shown in Figure 6, after removal of the surface layers, the lamina surface appeared homogeneous in composition, with average contents of 73wt% gold, 15.60 wt%Ag and 11.40 wt%Cu.

SEM examination was also carried out on the metallic pins used to fix the teeth to the gold-band. Figure 7A shows the lingual surface of the central incisor with massive presence of calculus deposits all around the pinhole. EDS measurements on the external surface of the pin gave evidenced a thick external deposit mainly formed by lead (Fig.7B), which in turn was almost totally covered by sulphur/oxigen-rich copper precipitates (Fig.7C). This evidence might be the consequence of the selective dissolution of copper from the gold alloy lamina, with the less subsequent redeposition on less noble lead metals, thus contributing to the formation of the copper-rich green patina visible on the teeth surfaces. Further studies are currently underway to better clarify the nature and constitution of the lead deposit onto the fixing pins.

Discussion and Conclusion

Dentistry has evolved over time from a rather barbaric practice to a technologically advanced industry, and even early civilizations recognized the benefits of tooth replacement with different kinds of appliances. Many examples of dental appliances derive from Etruscan contexts over 2,500 years ago and the technological practice was described by ancient literary sources from Egyptians, Greeks, and Romans, but material evidences are scarce[2-6].

Already in the 14th century Guy de Chauliac (1300-1368) described the replacement of lost teeth with those of another person or with artificial teeth made from oxbone, which may be fixed in place by a fine metal ligature. He claimed that such a device could last over time[7].

The most important texts describing dental appliances are the books by Ambroise Parè (1510-1590) and especially the one by Pierre Fauchard (1678-1761), who is considered the father of modern dentistry.

Parè prescribes the use of artificial teeth made of bone or ivory to replace lost anterior teeth in order to correct deformity and pronunciation of the mouth. The artificial teeth should be joined together and to the natural teeth with a thread of gold or silver or with a common thread of silk or flax[8].

Pierre Fauchard described more in detail the process by which artificial or natural teeth could be used for the replacement of multiple teeth[9]. Fauchard's technique consisted in producing holes in the prosthetic teeth and fixing them to a gold band positioned anteriorly and posteriorly through simple threads. Fauchard claimed the longevity of restorations by this technique: "Teeth and artificial dentures, fastened with posts and gold wire, hold better than all others. They sometimes last fifteen to twenty years and even more without displacement. Common thread and silk, used ordinarily to attach all kinds of teeth or artificial pieces, do not last long"[10].

Figure 8 shows the Parè and Fauchard appliances to hold loose teeth in place: they were made by two gold bands on the lingual and buccal surfaces, and were blocked inside the teeth with simple strings. The Guinigi prosthesis seems more complex because the gold lamina ran inside the dental roots and the teeth were blocked with golden pins, compared to that of Fauchard in Figure 8. Moreover, the Guinigi prosthesis was anchored to the teeth still *in situ* through the lateral S-shaped ends, probably fixed with strings.

In conclusion, although the medical texts of the Early Modern Age describe the use of the gold band technology to replace missing teeth, no direct evidence of such a device has been found so far. Therefore, the dental prosthesis found in the multiple tomb of the Guinigi family provides the first archaeological evidence of a dental prosthesis in this period.

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Figure 1 - Golden dental appliance of the Guinigi tomb. A: buccal view, B: lingual view, C: incisal view, D: inferior view.

124x85mm (300 x 300 DPI)

Figure 2 - Magnification (3x) of the root apexes showing small cuts, furrows and abrasion activity. Gold band inserted in aligned teeth.

124x73mm (300 x 300 DPI)

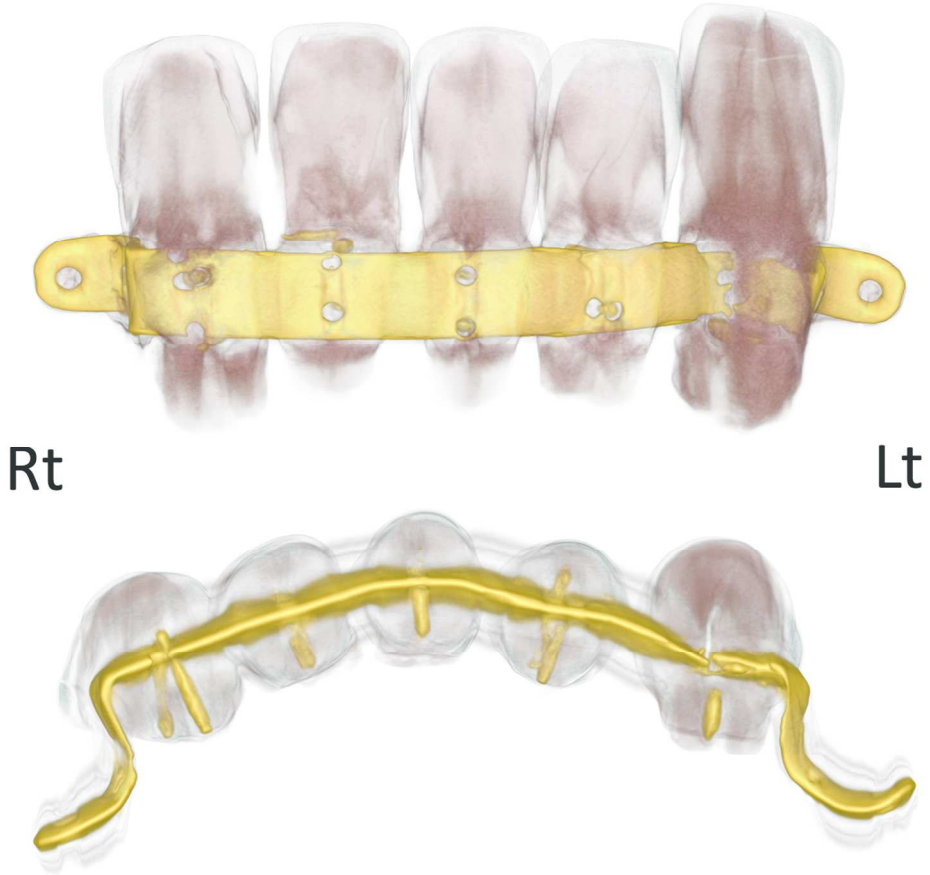

Figure 3 - Micro-CT images of the prosthesis revealing the small pins inserted into the root and blocking the teeth at the internal gold-lamina.

124x127mm (300 x 300 DPI)

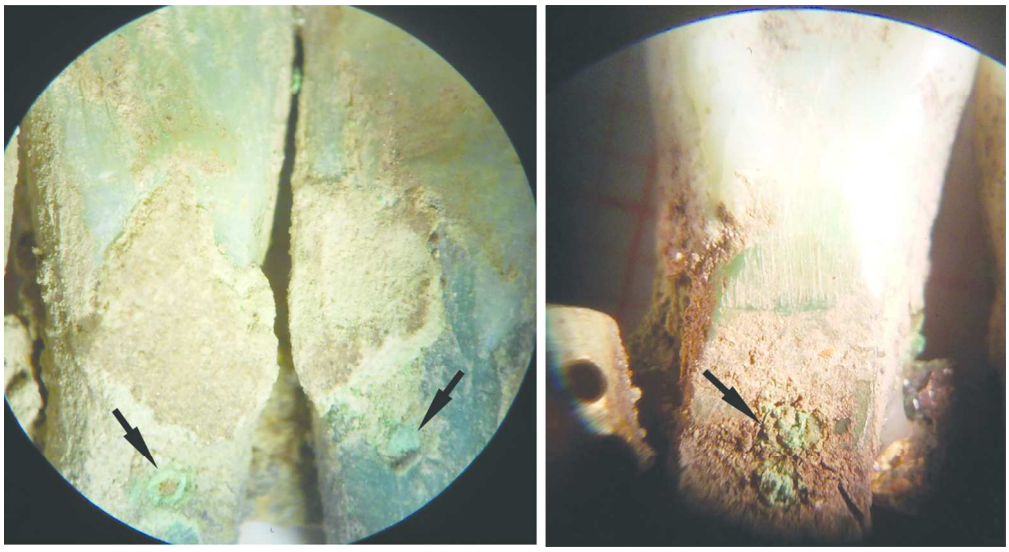

Figure 4 - On the left: Lingual surface of the two central incisors where two holes with golden pins (arrows) are visible under calculus deposits; 5x magnification. On the right: left canine (LC) showing an artificial wear facet with microstriations localized at the tooth neck on the lingual surface; 5x magnification.

124x67mm (300 x 300 DPI)

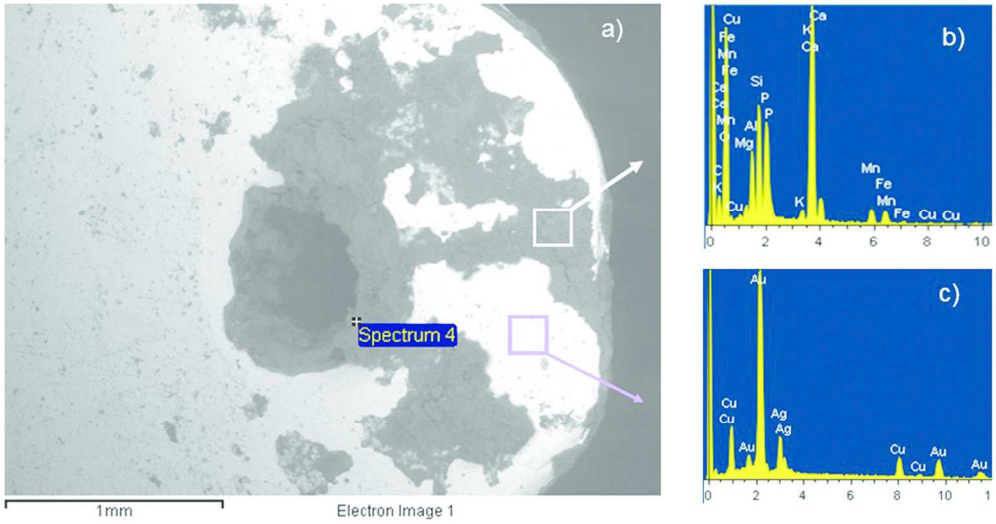

Figure 5 - Electron micrograph (SEM, BSE) of the right S-shaped end of the gold lamina: a) evidence of dark-coloured surface deposits (dental calculus); b) x-ray spectrum arising from the region of the deposit and c) x-ray spectrum arising from a deposit-free region.

124x65mm (300 x 300 DPI)

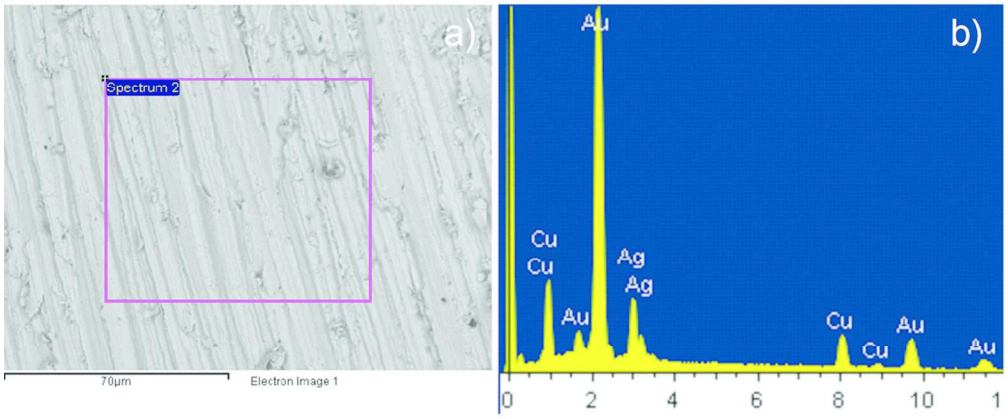

Figure 6 - Electron micrograph (SEM-BSE) of the golden lamina: a) scratched surface after grinding ‼ ┼ and b) x-ray spectrum arising from the region indicated in the figure.‼ ┼

124x53mm (300 x 300 DPI)

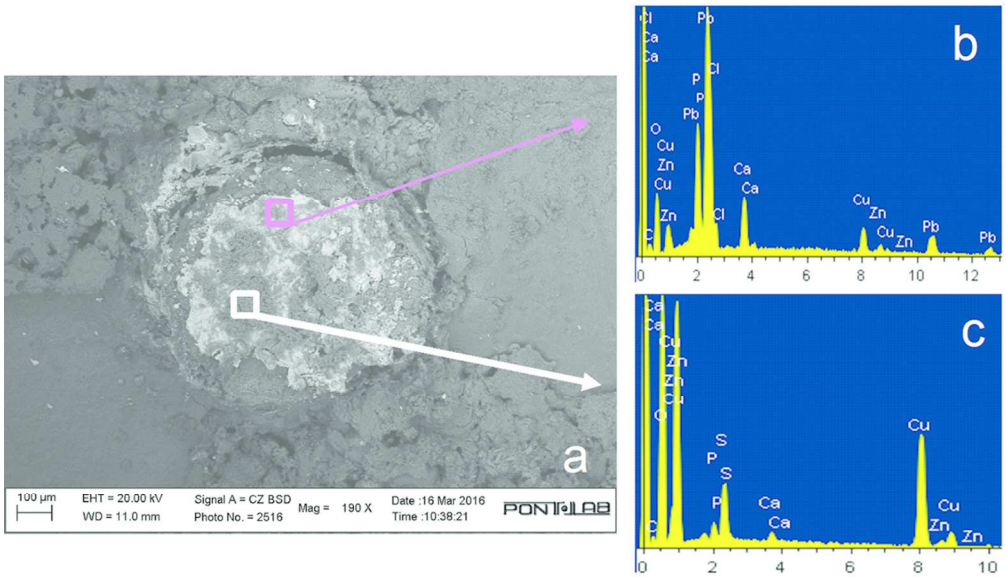

Figure 7 – Electron micrograph (SEM-BSE) from the fixing pinhole on the lingual surface of the central incisor: a) evidence of thick calculus deposits all around the pinhole; b) x-ray spectrum from whiter regions, mainly consisting of lead (Pb) and c) x-ray spectrum from surface Cu-rich deposits (see text).

124x73mm (300 x 300 DPI)

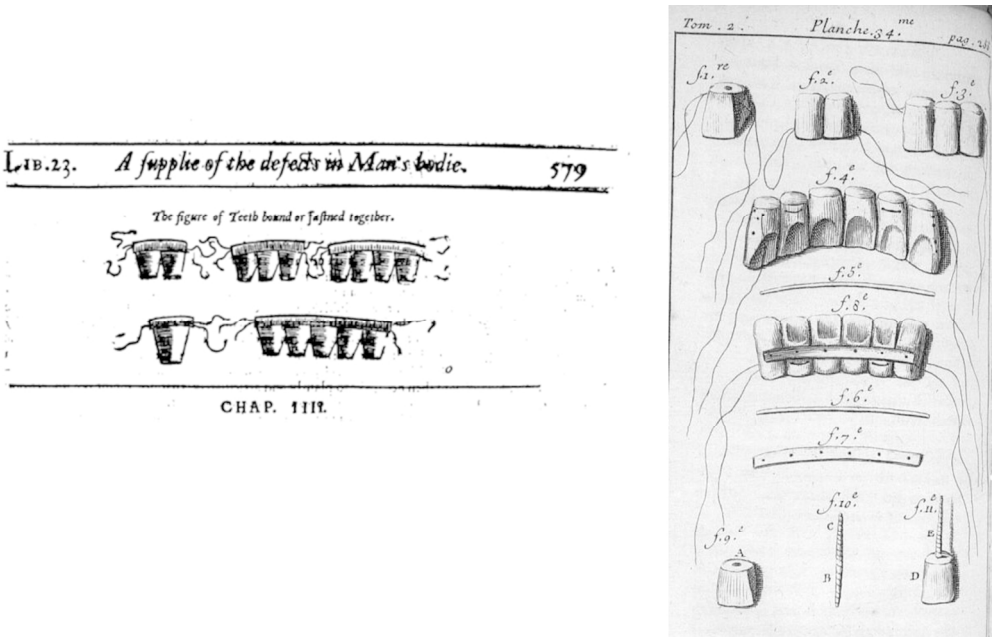

Figure 8 - Dental appliances depicted by Parè (1579) on the left and Fauchard (1746) on the right.

124x78mm (300 x 300 DPI)