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REVIEW ARTICLE

Evolution of facial prosthetics: Conceptual history and biotechnological perspectives

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ABSTRACT

The reconstruction of cephalic defect and more precisely from the face is not a recent issue. Indeed, the use of facial masks in a symbolic perspective was reported in ancient Egypt. Few references to facial prostheses are then found. It is really only with the work of the French surgeon Ambroise Paré that the first surgical techniques concerning facial epithetics are described. Techniques and materials tend to evolve over the centuries. But then came WWI, which marked a major turning point and brought to light the broken faces and the impact of maxillofacial trauma. Rehabilitation became a major issue in society. The war was a driving force for change from both a surgical and prosthetic point of view, revealing in particular such brilliant designers as the American sculptor Anna Coleman Ladd. Today, the profession is undergoing a major upheaval, linked to the growing development of biotechnological constructions. This historical review aims to retrace the evolution of the rehabilitation of facial substance loss over the ages and to outline the prospects for the foreseeable future. (*Int J Maxillofac Prosthetics 2021;4:2-8*)

Keywords

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INTRODUCTION

"Prosthetics reconstruction is the oldest branch of plastic surgery, predating even the crudest surgical attempts at reconstruction" according to Keith F. Thomas.[1] Restoring facial anomalies with some prosthetic appliance has certainly been one of the oldest rehabilitations of the human body because the symbolic richness of the face has always raised a singular need for social normality. This narrative review outlines the major steps of the evolution of facial prostheses throughout the centuries. The spotlight is on practitioners who have elaborated new concepts rather than on the techniques themselves (Fig 1). The first part of this article deals with the origins of facial prosthetics and its symbolic perspectives. The second part focuses on the revolutionary designers of facial prosthetics, such as Ambroise Paré (1510-1590) and Pierre Fauchard (1696-1718). Then, special tribute is paid to World War I (WW1) practitioners, including the American sculptor Anna Coleman Ladd (1878-1939). Finally, we propose the future evolution of facial prosthetics, with special emphasis on new biotechnologies.

ANCIENT HISTORY: THE EMERGENCE OF FACIAL PROSTHESES

The wearing of artificial parts on the face may have begun before antiquity, but this theory lacks supporting evidence.[2] However, archaeologists found an artificial artifact inserted in the left eye socket of a skull at Shahr-i Sokhta (Iran) that could be dated around 3000-2900 B.C.[3] The eye socket bore marks of thread, so the artificial eye was worn when death occurred. Moreover, in ancient Egypt tombs (about 2500 B.C.), gold masks have been found on mummies with cosmetic gold and silver coins.[4] These discoveries revealed the first known techniques of facial prosthetics and highlighted the social importance of the face during ancient times.

Ancient India punished adultery by amputating the nose, ears and hands.[5] The Sushruta Samhita, a famous treatise on Indian medicine from the Vedic era, reported surgical reconstructions of the nasal pyramid with a cutaneous flap taken from the frontal region. The chances of success were lower

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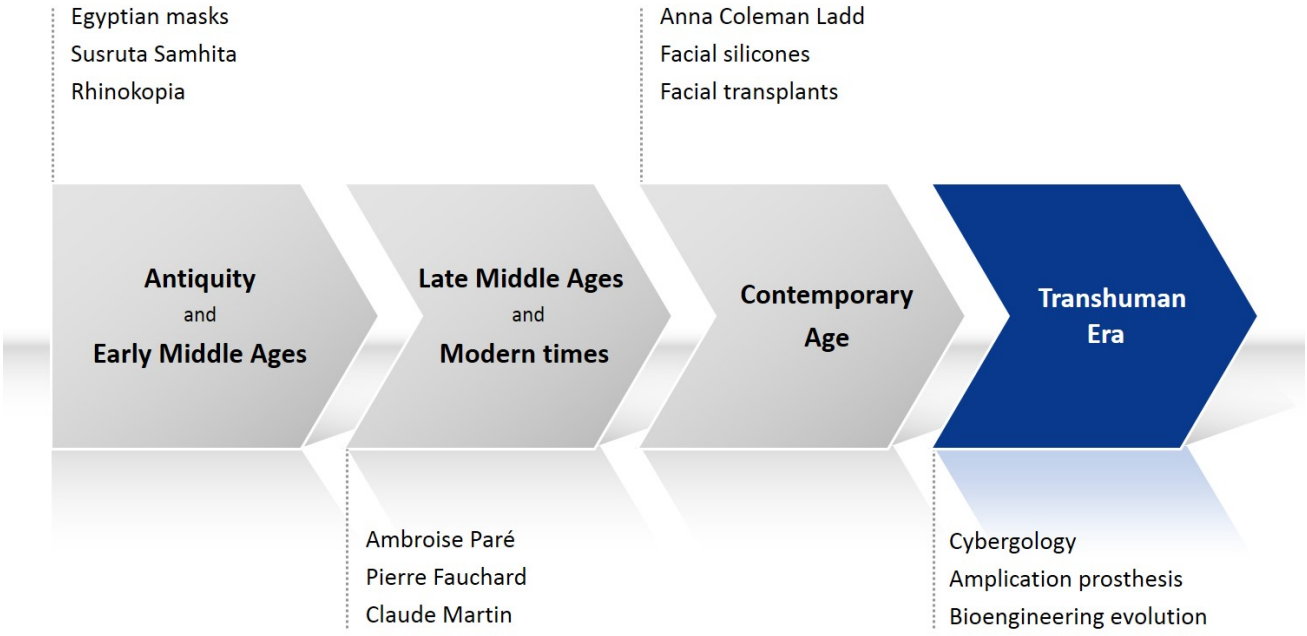


Fig 1. Chronological frieze: the milestones in the history of facial prosthesis through the great periods of human history.

than today, which raises the hypothesis of undescribed attempts at prosthetic reconstruction. Punitive mutilations were also found in Mesopotamia, by the king Hammurabi (1810-1750 BC) although known for his medical and moral codes. The retaliation, punishing those who mutilated one of their peers, certainly encouraged some attempts at surgical grafting for replacing missing parts.[6] Writings from the Greco-Roman period made little mention of facial prostheses: Hippocrates, Galien, and Celse were more interested in long bone fracture reductions and restraints than in treating maxillofacial defects. However, some Latin inscriptions found in Pompei and Herculanum indicated the doors of “medicus ocularis” and “faber ocularis”, suggesting the existence of an ocularist profession.[7,8]

POST-CLASSICAL HISTORY: FACIAL PROSTHESES OF THE KINGS

During the Middle Ages, the Byzantine belief was that a man with a severed nose could not become emperor (“rhinokopia”). The emperor Justinian (482-565) had his nose mutilated on Leonce’s order.[9] Reinstated for a second reign in 705, Justinian used a gold prosthesis to mask his nasal blemish during his second reign, and was nicknamed "Rhinotmete". The rhinokopia restriction was then replaced by the blindness restriction, removing the emperor Philippicos in 713 from his throne. Otton III (980-1002), the Emperor of the Holy Empire, made a historical visit in 1000 AD to the tomb of Charlemagne at Aix-La-Chapelle (France). Otton removed a tooth of Charlemagne as a relic and replaced a piece of the cadaver’s broken nose with a gold plate.[10] Around the same time but further east, Abulcasis (936-1013) described facial prostheses made of ivory.[8,11] Nicknamed the “prince of doctors”, Abulcasis was known in odonto-stomatology for his multiple surgical descriptions during the time of the Caliphate of Cordoba.

MODERN HISTORY (EARLY MODERN PERIOD): BIRTH OF MAXILLOFACIAL PROSTHETICS

Maxillofacial prosthetics was really born with Ambroise Paré (1510-1590), whose clinical knowledge tinged with military medicine provided the first maxillofacial prostheses with surgical anchorage (Fig 2). After three years of learning anatomy through human dissections, he moved from the largest hospital in the kingdom of France, the Hôtel-Dieu in Paris, to Vitré to acquire practical knowledge of surgery from a barber.[12] He then became a military surgeon, dealing with heavy mutilations, until being appointed “Surgeon of the King” of France (for Henri II and Charles IX). As an anecdote, Paré and André Vésale (Surgeon of the King of Spain) unsuccessfully tried to save Henri II from a severe maxillofacial injury during the Tournelles tournament (1559). In his book Dix livres de chirurgie avec le magasin des instruments, Ambroise Paré describes many surgical and prosthetic procedures, including facial epitheses by use of gold, silver, paper and linen, glued and held in place by small laces (Fig 3).[13] He also described orbital prostheses and ocular shells.

The ocular shells were first described a century ago on the Venetian island of Murano.[14] However, the first real corporation of ocularists was formed in Germany, and their knowledge spread all over Europe, educating the first reported French ocularists Alphonse Desjardins and Auguste Boissoneau. At this time, the famous Danish astronomer Tycho Brahé (1546-1601) named a supernova in the constellation of Cassiopeia, and lost the central portion of his nose during a duel relating to the birth of Pythagoras. A silversmith made him different gold and silver nasal prostheses to mask his gaping stigma.[15] Still around the same time, the "miracle surgeon" Gaspare Tagliacozzi (1545-1599) was one of the first to perform facial surgery. In Chirurgia nova de nasium, aurium, labiorumque defectu per insitionem cutis ex humero, he described his protocol for grafting a nose from a flap of arm flesh.[16] This efficient and innovative operation, known as the "Italian method", was still used more than four centuries later, during WWI.[17]



Fig 2. Ambroise Paré (1510-1590), father of modern surgery and of maxillofacial prosthetics (French Stamp, 1943).

During the 18th century, Pierre Fauchard (1678-1761) added a significant milestone to facial prostheses. His book Le Chirurgien-Dentiste ou Traité des Dents (1727) was the first of its kind dealing with dentistry as a comprehensive medical specialty that included maxillofacial prosthetics (Fig 4). Considered the father of dental surgery and orthodontics, he revolutionized this handicraft, worked all his life to raise the profession as a science and fought against charlatans. Through his encyclopedic writings, he set the foundations of the maxillofacial dentistry trade for future generations to improve on. Among other techniques, Fauchard described the processes of making facial epitheses with papier-mâché and silver.[18]

MODERN HISTORY (LATE MODERN PERIOD): MATERIALS AND TECHNIQUES FOR FACIAL PROSTHESIS

During the industrial revolution (19th century), the new materials available for facial prostheses considerably improved their appearance. The rigid and uncomfortable gold and silver were replaced by lighter materials. Epitheses were then more aesthetic, more functional, and became effective therapeutics to mask disfigurement. Indeed, in 1851, Goodyear obtained vulcanite by incorporating sulfur into rubber. This easy-to-handle and colorable product could be used in both hard or soft forms and became a major component of conventional dental prostheses and facial prostheses. Norman Kingsley (1829-1931) and Apoléoni Preterre (1821-1893) also described the use of vulcanite for facial prostheses (in 1864 and 1866, respectively). Then from 1879, Kingsley used celluloid.[19]

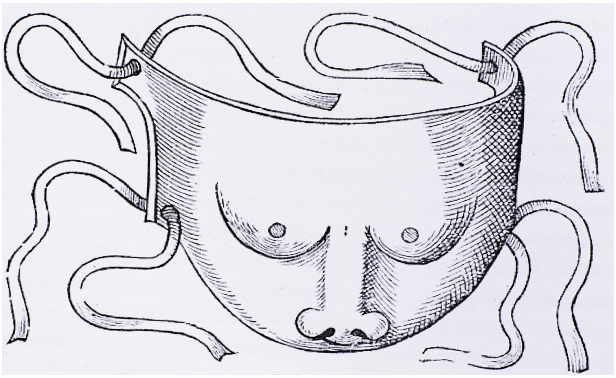


Fig 3. Face mask made of glued paper and linen, painted and enameled.[13]

At the end of the 19th century, a French dentist, Claude Martin (1843-1911), gave maxillofacial prosthetics a new dimension by combining maxillofacial surgery and dental prosthetics. For the first time in De la prothèse immédiate appliquée à la resection des maxillaires, Martin used the terms "surgical" and "prosthesis" together.[20] He described the use of translucent ceramics for nasal prostheses after amputation, providing satisfying skin simulation. Around the same time, Karl Henning (Austria) proposed an original and still-used method for restoring noses, ears and cheeks.[21] After creating an impression of the patient's face with plaster, the missing facial organ was reconstructed with wax on the plaster model. Then, the wax prototype was enclosed in a multi-part muffle and removed by lost-wax casting.

Gelatin and glycerin paste were poured into the space within the muffle with vulcanite or rubber. This paste was colored with yellow ochre and vermilion pigments to mimic the skin color. When the dough hardened, the artificial organ was removed from its mold and edges were regularized. For clinical fitting, the epithesis was glued with some mastic solubilized in ether. This revolutionary method offered aesthetic and comfortable epitheses made with an inexpensive and easy-to-use process in a short time. Their characteristics were closer to human tissue than all previous attempts.



Fig 4. Pierre Fauchard (1678-1761) father of dental surgery and orthodontics (French Stamp, 1961).

MODERN HISTORY (LATE MODERN PERIOD): WWI AS A TURNING POINT

During WWI, more than 60 million men fought for four years; the war produced 500,000 cranio-facial injuries, including 10-15,000 “serious facial injuries”. Although these maxillofacial injuries were commonly treated, their prevalence increased considerably and surpassed the efforts of the rare specialists of the field, such as prosthodontists, dental technicians and maxillofacial surgeons.[22] However, the large number of “broken-face” patients contributed to the development and recognition of maxillofacial prosthetic rehabilitation.[23] In 1917, the American sculptor Anna Coleman Ladd (1878-1939) ran workshops to make facial masks for the WWI “broken faces”. Working from the writings of Francis Derwent Wood,[24] she collaborated with French maxillofacial surgeons Hippolyte Morestin and Léon Dufourmentel and gave a series of lectures about facial prosthesis fabrication at the Pasteur Institute.[25,26] On March 18, 1918, she and the French sculptor Jane Poupelet signed a contract with the American Red Cross to run workshops for masks.[27] After obtaining official approval from the Armed Forces Health Service, Coleman Ladd then traveled to various French regions to help disfigured patients.[28] She was awarded the Legion of Honor in 1934 for her work and dedication to the WWI “broken faces”. These numerous patients faced psychosocial difficulties in reintegrating with the family and society. The recognition of the Studio for Portrait Masks (1918-1920) by maxillofacial specialists, military authorities and French political circles helped dictate laws for protection of “broken faces”. The Union of the Wounded Faces emerged from this need and provided shelters for this new community. The French “broken faces” association (Gueules Cassées) still exists and protects mutilated soldiers.[29]

The First World War had already highlighted the importance of surgical-prosthetic symbiosis. In 1917, Major Valadier, a French-American dental surgeon and Captain H. Lawson Whale, a plastic surgeon, published on the interest of multidisciplinary management of maxillofacial trauma.[30,31]

CONTEMPORARY TIMES: FROM SILICONIZED PROSTHETIC SKIN TO FACIAL GRAFTS

The second half of the 20th century was marked by progress in organic chemistry and the advent of silicone. Silicone was discovered in 1934, when researchers from Dow Chemical and Corning Glass developed a new electrical insulation by combining the properties of glass with those of organic plastics. In 1943, the first silicone applications were military-oriented, dampening the vibrations of Air Force navigation tools and isolating spark plugs from aircraft and marine engines.[32] In 1959, a Dow Corning Centre for Medical Research was established to clarify and develop, in collaboration with hospital research, the indications for silicone in medicine and surgery. In 1962, Silastic Medical silicone elastomers were available to the medical trade. Silicone is still the preferred material for making epitheses, among other prostheses, such as breast prostheses (Fig 5).[33] In 1979, Anders Tjellström performed the first implant-supported auricular epithesis, and the osseointegration works of Per-Ingvar Brånemark and Tomas Albrektsson improved bone fixation possibilities for all implant-supported prostheses (Fig 6).[34, 35]

THE BIOTECHNOLOGY FUTURE OF THE MAXILLOFACIAL PROSTHESIS

The current facial prosthetics evolution is still driven by the development of materials and technologies (computer-aided design/computer-assisted manufacturing [CAD/CAM]).[36-38] However, facial prostheses are still the complementary and reliable alternative that fills the gap left by the limitations of surgery. This may

be the case for the surgical rehabilitation of patients after exenteration, which may be limited by the volume of the defect, the general condition of the patient or the wish not to undergo further surgery.[39] In this case referral to a maxillofacial prosthetic team is recommended. The surgical-prosthetic symbiosis is an indispensable prerequisite for the realization of an aesthetic rehabilitation. The use of acrylic or silicone elastomer materials allows today to obtain aesthetic, light and economical prostheses.[40] In order to add animation to the gaze of patients rehabilitated by ocular prosthesis, some practitioners have replaced the static iris by a dynamic photo iris.[41] Indeed, surgery has always been the main driving force for maxillofacial prosthetics evolution.[36] The rationale behind the "surgery-first" trend is the patient's preference for a definitive versus a "provisional" treatment.



Fig 5. Silicone nasal prosthesis (Rangueil Hospital Group, France).



Fig 6. Ombredanne's bar: the beginning of extra-oral implants (Rangueil Hospital Group, France).

At the beginning of the 21st century, facial rehabilitation made new inroads with the first attempts at facial transplants and the subsequent ethical questions. To date, more than a dozen facial transplants have been performed worldwide (France, United States, China and Spain). The world premiere of facial transplants was held in France in 2005 with the collaboration of Amiens University Hospital Center, the Catholic University of Louvain (Belgium), and Lyon University Hospital Center. For this first (partial) facial transplant on a 38-year-old woman, a triangle graft including a nose and mouth was performed. In 2007, Henri-Mondor Hospital (Paris-Créteil, France) performed the second face transplant on a 27-year-old patient with severe Von Recklinghausen's disease, an incurable pathology with facial distortion. In 2010, a 30-year-old Spaniard, accidentally disfigured five years earlier, benefited from "total grafting of the face," the face from a brain-dead donor, at Vall d'Hebron University Hospital. This operation required a team of 30 surgeons, anaesthetists and nurses, led by Joan Pere Barret, head of the department of plastic surgery at the Barcelona hospital. Then in 2017, a first post-mortem human head transplant was performed by Sergio Canavero and Xiaoping Ren, paving the way to a future procedure with a live recipient patient.[42]

Some other directions for facial prosthesis evolution could emerge from the increase in converging technologies, such as nanotechnology, biotechnology, informatics and cognitivism.[43] In that transhumanism progressively affects medical therapeutics by adding biotechnology devices to patients, facial prosthetics will certainly help increase the patient's biological functions. Benefitting from advances in neurosciences, haptic medicine, and nanotechnology, facial prosthetics could be involved in creating cyborgs, the association of man and machine. The term "cyborg" was coined by Manfred Clynes (1925-2020), a neurophysiologist in the 1960s, as a contraction of "cybernetic" and "organism". It was reintroduced into the scientific literature by Donna Haraway, biologist, anthropologist and philosopher, in her *Cyborg Manifesto*.[44] Instead of being passive, facial prostheses could ensure true neurophysiological interactions with their wearers via the complex phenomena of hybridization and vicariance (substitution). These new devices would become closer to "maxillofacial amplification prostheses" by improving the world perception through restored sensory properties and new extra-sensory properties.

A recent example of cybergology evolution was from Stelarc, the artist who in 2006 conceived the Extra Ear project.[43] The morphology and structure of an auricular pavilion was designed and equipped with a miniature microphone that recorded the artist's surrounding noises. Then in real time, Internet users could intercept the sound frequencies around the artist via his website. The concept was to provide an extra-sensory function through hybridization to create a "connected humanity". Stelarc stated that beyond the concept of hybridization, this piece of art represented access to new biotechnology to exceed one's own sensory and motor abilities.

In 2007, Stelarc completed his project and implanted in its forearm a biopolymer ear structure that was gradually covered by skin and became an internalized structure. The hybridization was achieved by the intimate histological connection of the bio-object with its skin substrate. Equipped with a receiver, this third ear allowed Stelarc to become an internet portal providing others with the possibility to use his body. The hybridized body with microphone bioprosthesis became a collective experience.

These technological devices may also benefit from the bioengineering revolution that will soon allow for bioprinting of graft prostheses with an intimate integration in the organic maxillofacial support.[45] Indeed, the CAD/CAM guidance of free vascularized flap transplantation with dental implant placement has been a revolution in the field.[30] In this context, an interesting improvement would be to provide the patient with a composite graft CAD/CAM-driven to match perfectly the defect, being scalable, on-demand, with complex anatomical design, and layer-by-layer controlled distribution (Fig 7).[46] Ear and nose reconstruction by tissue engineering can benefit from 3D printing, replacing the cartilage scaffold with printed polymers.[47,48] In China, some of these 3D-printed ears were recently transplanted in patients with microtia, with follow-up periods ranging from 6 months to 2.5 years.[33] Most of the protocols usually begin with designing the missing organ prototype from medical imaging of the patient and 3D printing the piece with a biodegradable material to obtain the scaffold with the organ shape. In the meantime, the patient's chondrocytes are cultured in vitro for expansion. Then, cells are seeded on the scaffold before transplantation under the skin. In terms of 3D printing of biological components, the most mature studies reported protocols for printing with a biodegradable scaffold, biological proteins and chondrocytes at the same time.[48] A proof-of-concept ear was even bioprinted with a conductive electronic antenna perceiving sounds that the normal human ear could not.[48] The infused silver nanoparticles enabled a readout of signals from cochlear-shaped electrodes, thus enhancing auditory sensing for radiofrequency reception and opening the possibility for listening to stereophonic music. Human grafting of bioprinted facial parts is not yet available but, in the future, could be delivered in situ, directly in the patient to fill in the defect and regenerate missing tissue.

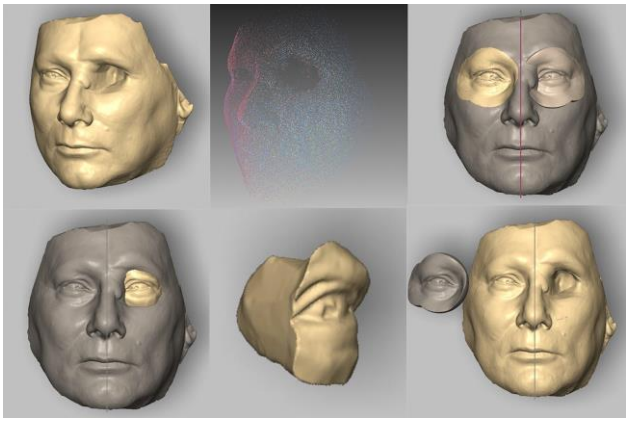


Fig 7. Digital advances in facial prosthesis.

CONCLUSION

The desire to preserve or restore facial features is an obvious human concern that harks back to the most remote times of humanity. Maxillofacial prosthetics constitutes a very ancient dental and medical discipline whose purpose is to replace an absent or altered maxillofacial organ with an artificial device. The prosthesis may be a bio-object whose design goes beyond its trivial conception because it carries psycho-social considerations associated with identity and relational and symbolic issues. With this historical account, we highlight the evolution of facial prostheses over the centuries, paying tribute to their designers, in order to better understand the current and future challenges. The facial prosthesis of tomorrow, at the singular crossroads of cybergology and bioprinting, will incorporate transhumanist aspirations. The improved prosthetic human may pass from the status of a patient to that of a hybrid, whose fate will have to be determined within the framework of a phenomenological approach.

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