

Introduction to electroforming

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ABSTRACT. Electroforming can be defined as an industrial technology for making metal pieces by electrolytic deposition of metallic layers of varying thickness, followed by the removal of the substrate and the exclusive preservation of the newly formed piece. In English, the term ‘electroforming’ is used exclusively, regardless of the technological field, while in German the term ‘galvanoforming’ is mainly utilized. In Romanian, an equivalent term is ‘galvanoplastie’ (galvanoplasty/electrotyping), but its meaning prevalently refers to the obtainment of other pieces, such as working models. The re-launch of gold-based electroforming as a technological procedure, by Rogers and later by Wismann, by developing non-toxic sulfite electrolytes, resulted in its use in fixed prosthodontics, especially in the field of unidental prostheses.

KEYWORDS: galvanoforming, electroplating, electroforming, electrolyte.

Electroforming can be defined as an industrial technology for making metal pieces by electrolytic deposition of metallic layers of varying thickness, followed by the removal of the substrate and the exclusive preservation of the newly formed piece. In the Romanian literature, the term ‘galvanoforming’ is used with reference to the above-mentioned procedure. To eliminate any doubts regarding terminology, a few aspects should be mentioned:

- the term ‘galvanoforming’ is equivalent to ‘electroforming’, through it should be noted, in Romanian, the term ‘galvanoforming’ is used exclusively in dental technology, where in other fields the term ‘electroforming’ is prevalent. In English, the term ‘electroforming’ is used exclusively, regardless of the technological field, while in German the term ‘galvanoforming’ is mainly utilized. In Romanian, an equivalent term is ‘galvanoplastie’ (galvanoplasty/electrotyping), but its meaning prevalently refers to the obtainment of other pieces, such as working models.

- the major difference between galvanoforming/electroforming and all other technologies reunited under the umbrella term of galvanization (electroplating, electrotyping, etc.) is that the latter are surface coatings modifying only the appearance and/or resistance to corrosion and other, especially mechanic, properties of the substrate on which the deposition takes place. No new piece is “formed”. The difference rather refers to the applicability of the two procedures, as they are technologically identical to some extent, and they cannot be dissociated historically and as far as the development and improvement of technologies is concerned.

In dental technology, electroforming is a new and “noble” technology for making metal pieces, which consists of the electrodeposition of a metallic layer on the surface of a duplicate abutment, until the obtainment of a cap that is 200 - 300 μm thick (1). The deposited metal is pure gold (99.96 % purity, according to Diedrichs-Rosenhain). The electroforming process takes place in dedicated installations, manufactured by established companies in the field of dental technology (Heraeus - Kulzer, Schütz - Dental, Wieland, Hafner, etc.).

The term “galvanic” is derived from the name of Luigi Galvani (1737-1798), Italian physician and physicist, professor of anatomy at the Accademia delle Scienze di Bologna, who was the first to demonstrate the relation between electricity and biology, obtaining muscular contraction by applying electricity on the nerves of a dissected from limb. He also studied the possibility of transforming chemical energy into electric power (direct current - galvanic current). The results of his experiments are still applicable nowadays, namely in the field of accumulators.

The reverse process to the one described by Galvani is represented by electrolysis, that is the initiation of chemical reactions with the help of electric power (8).

The first person to achieve the galvanodeposition of gold was the Italian chemist Luigi Valentino Brugnatelli (1761-1818), a good friend of Alessandro Volta (1745-1827). Shortly after Volta perfected the first source of direct current, currently known as “voltaic pile”, Brugnatelli started using this source for the purpose of galvanodeposition of gold on a silver substrate. Around the year 1805, Luigi Brugnatelli wrote in the Belgian Journal of Physics and Chemistry: “I have lately gilt in a complete manner two large silver

medals, by bringing them into communication by means of a steel wire, with a negative pole of a voltaic pile, and keeping them one after the other immersed in ammoniuret of gold newly made and well saturated". Unfortunately, due to his differences with Napoleon Bonaparte, Brugnatelli was excluded from the French Academy of Sciences, leader in the field at that time, and his activity has remain very little known.

Moritz Hermann von Jacobi (1801-1874, Boris Semjonowitsch Jakobi since 1842), German physicist and engineer, professor at the St. Petersburg Academy of Sciences, where he worked with Dmitri Mendeleev, is believed to have been the founder of electrotyping. In 1838 he described, for the first time, the applications of electrotyping in printing, by developing the electrotype (a printing press obtained by copying the original matrix by electrotyping). He was the first to use galvanic technology for the purpose of obtaining new pieces, independent of the substrate of deposition. His concerns for electrotyping are found in the multiple papers he published: "Ober die Entwicklung der Galvanoplastik" (Bulletin de l'Academie Imperiale des Sciences de St. Petersburg, 1843); "Ober die galvanische Vergoldung" (Bulletin de l'Academie Imperiale des Sciences de St. Petersburg, 1843); "Einige Notizen liber galvanische Leitungen" (Bulletin de l'Academie Imperiale des Sciences de St. Petersburg, 1843); "Galvanische und electromagnetische Versuche" (Bulletin de l'Academie Imperiale des Sciences de St. Petersburg, 1845-47, 1848-50); "Vorlaufige Notiz liber galvanoplastische Reduction mittelst einer magneto-electrischen Maschine" (Bulletin de l'Academie Imperiale des Sciences de St. Petersburg, 1847); "Die galvanische Pendeluhr" (Bulletin de l'Academie Imperiale des Sciences de St. Petersburg, 1847); "Note sur la production de depots de fer galvanique" (Bulletin de l'Academie Imperiale des Sciences de St. Petersburg, 1869); "Notice sur l'absorption de l'hydrogene par le fer galvanique" (Bulletin de l'Academie Imperiale des Sciences de St. Petersburg, 1870); "Sur la fabrication des etalons de longueur par la galvanoplastie" (Bulletin de l'Academie Imperiale des Sciences de St. Petersburg, 1872).

Around 1840, the brothers Henry and George Elkington from Birmingham, England, developed the principles of Brugnatelli and succeed in obtaining a patented technology (in co-operation with John Wright) for galvanic gold and silver coatings, from cyanide solution. The possibility of electroplating other metals soon appeared. By 1850, England had already perfected technologies for shiny nickel, tin, zinc and copper electroplating, with industrial or commercial applications.

The introduction of electrotyping in dental technology occurred in the second half of the 19th century, and the technologies were perfected in early 20th century. Thus, as early as 1929, Gysi was successfully

using the galvanic technique to make bases for complete Ni dentures.

In 1935, Damiano and Viverihofi perfected the technology for making abutments through electrotyping. It allowed obtaining abrasion-resistant and high-precision models. It was abandoned, however, with the emergence of class IV gypsum (10).

The use of Au electroforming for the purpose of obtaining fixed prosthetic pieces was initiated by Rogers and Armstrong as late as 1961, in order to obtain incrustations (5). In 1962, the two Australians described a technology for making gold incrustations, achieving, in a first phase an electroformed cap from pure gold, which was then filled with a noble alloy with high gold content, by overcasting. Between 1970 and 1980, the same Rogers expanded the electroforming technique, introducing mixed metal ceramic crowns with an electroformed metal component. For the first time, in 1979, Rogers described in detail the technology for making mixed galvano-ceramic crowns (4). The disadvantages of the Rogers system consisted of using an electrolyte bath in which the gold to be electroplated was in the form of a highly toxic complex cyanide combination cu (potassium dicyanoaurate $K[Au(CN)_2]$), a procedure still used, although sporadically, in jewelry. Due to this fact, Rogers' technique was abandoned.

In 1981, following Wismann's research, a sulfite-based electrolyte bath with no content in toxic substances was obtained, with which an electroformed golden cap was made. In 1983, Wismann patented the Platamic® system. The development of the same technique resulted in the 1988 advent of the GAMMAT®12 system, specially designed for dental laboratories.

The improvement in the above-mentioned system by the Gramm-Technik company (Tiefenbronn-Mühlhausen) lead to the GAMMAT®11C system, which allows making 6 caps simultaneously. The subsequent achievements of the company, the GAMMAT®Free and GAMMAT®Easy devices, are fully automated systems, which can perform both electroforming, and the gilding of various cast pieces (main connectors, clasps, telescope systems etc.). Finally, the last device marketed by Gramm, GAMMAT®Control, had the facility of calculating the needed volume of electrolyte, as well as electric parameters, thus eliminating almost entirely the probability of human error.

In 1986, Wieland Dental und Technik company (Pforzheim, Germany) became interested in making an electroforming system and succeeded in developing the AGC® (Auro Galya Crown) system. So far, AGC® technology has been the basis for six models of electroforming devices, AGC®5 process, AGC® Micro and Micro Plus, AGC® Comfort, AGC® Micro Vision, AGC® Speed, the last of which is the fastest and most advanced (electroforming in two hours). In the ensuing

years, several companies marketed systems dedicated exclusively to electroforming: Helioform® HF600, HF300 and Helioform® Vario (Hafner, Pforzheim), Preciano® and Preciano® IQ (Heraeus-Kulzer), El-Form® (Schutz-Dental), Solaris® (Dentsply DeguDent).

The galvanic technique also has industrial applications, galvanization (in the sense of anticorrosive or esthetic coating) being practiced in several domains: jewelry, electronics, aeronautics, rotating or sliding precision elements, home appliances, construction materials, etc.

PRINCIPLE.

As mentioned before, electroforming is the obtainment of metal pieces by galvanic plating on a substrate (duplicate gypsum abutment), followed by the removal of the substrate. Due to the procedure for making the metallic structure (atom-by-atom electrolytic deposition), the resulting piece has very precise adaptation on the abutment; the average value of the marginal space is 18 µm after the cementation of prosthetic restorations (51), a value which is impossible to obtain in the case of casting (fig. 1). In addition to the precise adaptation, electroformed prosthetic pieces also have other advantages:

- the small thickness of the metallic scaffold allows both saving noble material (a cap corresponding to a premolar of medium size weighs 0.3 – 0.4 g on average), as well as saving hard dental tissues, 1.2 mm tooth stripping being sufficient (1 mm for the ceramic plating and 0.2 mm for the metal scaffold). It is, thus, often possible to coat the lower incisors with mixed

galvano-ceramic crowns without having to devitalize the teeth for prosthetic purposes;

- the yellow, warm hue of pure gold yields outstanding esthetic results following the ceramic plating; esthetically, galvano-ceramic crowns equal fully ceramic restorations, with the advantage that they can be used to coat abutment with marked dyschromia;

- the unquestionable biocompatibility (99.96 % Au content) makes electroformed prosthetic restorations the treatment of choice for teeth with moderate periodontal damage;

- the electroforming technology excludes the possibility of reusing the material, an unrecommended procedure, but common in many dental laboratories in our country, in the case of casting;

- energy saving, electroforming requiring less than 1 % of the electric power needed for conventional melting and casting;

- electroforming is an automated procedure allowing the obtainment of predictable and reproducible results. Compliance with working protocol in electroforming guarantees the obtainment of a correct prosthetic piece;

- due to the precise adaptation of electroformed crowns on an abutment, the adaptation by subsequent processing and finishing are excluded, substantially reducing the time and effort made by the technician.

Galvanic deposition takes places directly on the duplicate abutment, the ionic gold in the solution transforming into atomic gold at the cathode, thus resulting in a chemically pure metal cap (fig. 2).

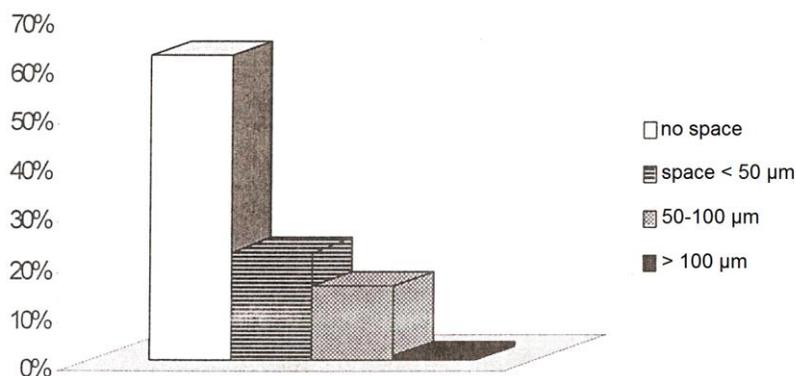


Fig. 1. The percentage distribution of the marginal space measured on 5 galvano-ceramic crowns; 1,057 measurements were made by microphotography, every 0.1 mm (6).

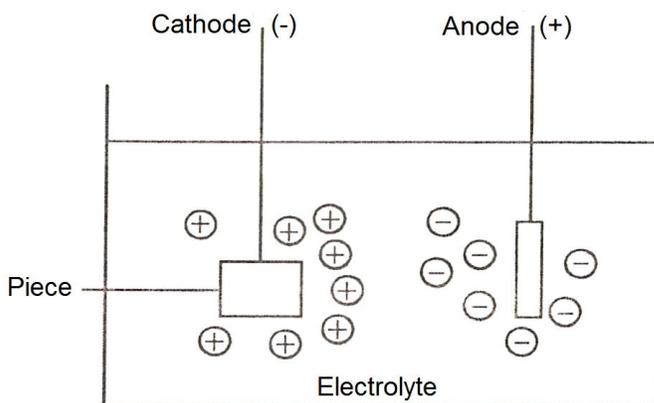


Fig. 2. The schematic representation of the electroplating principle (7).

Simplistically explained, the structure of an electroforming device comprises: an electrolyte bath (solution), two electrodes (an anode and a cathode) and a direct current source. To optimize deposition parameters, a solution heating source and an agitator are also necessary.

The anode is made, for most devices, from titanium, which is coated in platinum to improve its electric properties. The piece to be fi coated galvanically is the cathode. To make electroplating possible, an electroconductive varnish is applied to the surface of the gypsum abutment, containing silver particles. However, a decisive role in the electroforming process is played by the electrolyte (galvanic bath). On its composition depend the possible chemical reactions and the reaction products. The electrolyte is, in all marketed systems, an aqueous solution of a complex Au salt, in most cases a quaternary ammonium compound (for example $(NH_4)_3[Au(SO_3)_2]$). In addition to this, the electrolyte

also contains a series of substances, each having a certain role in the course of the electroplating process: a saline solution, a buffer system, stabilizers, organic addition for shine (table 1).

Another very important parameter in the electroforming process is represented by the direct electric current running across the entire system. Of capital importance for the quality of galvanic deposition is. Current density is the ratio between current intensity and the surface of the cathode. The operations take place at a 0.5 – 1.5 A intensity, corresponding to a 0.25 A/dm² current density. The slightest deviation from these values can lead to the prosthetic piece being compromised.

The working temperature is 45 - 65° C, depending on the system; the Preciano CL-GF device (Heraeus-Kulzer, Hanau, Germany) (fig. 3), works at a 61°C temperature. It takes about 7 hours to obtain a cap 0.2 mm thick. This is not necessarily a disadvantage, as the device may operate over night.

Table 1. Composition of the electrolyte and the mode of action of each substance.

Components of the electrolyte solution	Role of the substance
complex Au salt	source of Au atoms
saline solution	electroconductivity
buffer solution	maintains constant pH
stabilizers	neutralizes reaction products
organic addition	provides uniform deposition

Due to its multiple advantages, the electroforming technology is applicable to several branches of dental technology. The spectrum of applications ranges from unidental prostheses (inlays, onlays, partial crowns, mixed galvano-polymeric or

galvano-ceramic crowns), fixed or removable partial dentures, to bases for complete dentures or mesostructures and telescope systems in implantological prosthodontics (3).



Fig. 3. Preciano CL-GF device by Heraeus-Kulzer company (2).

CONCLUSIONS

Electroforming is the technology which makes it possible to obtain the most precise prosthetic pieces. Of all procedures used in dental technology, electroforming is by far the most precise. The need for precisely adapting the components of prosthetic restorations is mostly found in removable dentures, electroformed

retention elements being the application of choice for electroforming in dental technology.

Both skeletal dentures and acrylic overdentures, without a metal scaffold, can benefit from such retention elements. Likewise, galvanofomed maintenance means can be applied in both traditional prostheses and implantological prosthodontics.

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