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A BRIEF HISTORY OF DENTAL IMPLANTS

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Abstract

Teeth replacement through dental implants represents one of the oldest practices in the entire history of dentistry, being supported by archaeological findings and dedicated chapters in old medical textbooks. Ancient civilizations like Mayans, Egyptians, Phoenicians, or Chinese used amazing methods of implantology, and interesting materials like shells, bamboo, porcelain, iridioplatinum, or cobalt-chromium-molybdenum, connected using ligature wires made of gold, silver, linen or silk, or even real teeth, of human or animal origin. Over the time, dental implantology has evolved from rudimentary attempts to replace missing teeth, to experimental treatments with various materials, until reaching the point where implant-supported prostheses represent a highly predictable rehabilitation option. This historical perspective starts from ancient civilizations and emphasizes the main findings in every important phase of evolution of dental implants, providing a tour of the materials that were used, the main contributors and experiments that defined the science of implantology through time.

Key words: *dental implants, missing teeth, prosthetics, oral rehabilitation.*

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Introduction

Complete dentures represent a very important element in our lives, both from a functional, as well as from an aesthetical point of view. The loss of one or more teeth determines various problems like the worsening of chewing efficiency, a less attractive aesthetic look associated with a decrease in psychosocial wellbeing, or even problems regarding the capacity to pronounce correctly various sounds. Therefore, the necessity of replacing the missing teeth is obvious, in all periods of time, and it represents a constant preoccupation for humanity. No matter the time in history, a missing tooth would always represent an issue and a solution must be found – that tooth, by all means, has to be replaced. This represented a true priority for physicians from ancient times, and nowadays, implant-supported prostheses represent essential key elements in current modern dental medicine.

The origin of dental prostheses dates back a long time ago, since missing teeth have always posed two major problems: on one hand, eating may be more difficult, especially if more teeth are missing, and changes in the current diet may be applied, turning towards soft foods; on the other hand, a smile with missing teeth is hardly irresistible. In the dawn of humankind, the lack of an effective bite and the loss of the capacity to masticate food that was, at that time, minimally processed, represented a real threat for survival (Rajput, 2016). As time went by, food become more processed, softer, and posed less challenges for the human dentures. Missing teeth would no longer represent a life-or-death issue but would simply affect the variety of foods that one could consume. Still, it was a strong motivation to identify solutions to replace the lost teeth. When facial aesthetics also become an important factor related to self-confidence, self-esteem, and claimed self-handicapping, even more effort was put in maintaining one's denture, and in searching of reliable, functional, and aesthetically pleasant replacements teeth (Block, 2018). In fact, besides dental extractions which result in partial dentition, replacement of teeth using dental implants represents the oldest practice in the overall history of dentistry (Ali, 2019).

Potential solutions involved bridges, ligatures, or external teeth (either natural or artificial) placed in the space created by one or more lost teeth. Early procedures were performed either post-mortem, or during the patients' lifetime, but in this case, they would have been extremely painful, quite barbaric, with a major risk of death due to infections and contagious diseases, that were hardly controllable at that time, without proper medication. In fact, initial failures came from the lack of antibiotics, anti-inflammatory agents, and anaesthetics. In specific time periods in our history, dominated by religious restrictions, moral taboos regarding the intervention upon the human body also deprived patients from proper treatment (Hinds, 1979). So, the lifespan of a replaced tooth could have been expressed in days or months. It was not until the discovery of biocompatible materials and the development of less traumatic procedures, that dental implants could become more reliable, durable, and efficiently attached to the surrounding jawbone. In fact, the modern definition of a dental implant (also known as endosseous implant or fixture) refers to a surgical element that interfaces with the bone of the jaw and represents the support of a dental prosthesis (crown, bridge, denture, etc.). It is an artificial piece inserted directly in the jawbone following an invasive procedure, therefore a more appropriate definition could be that

of an artificial root (Pal, 2015) with the role to maintain various prosthesis in position and integrate them within the patients' natural denture. So, the key element is biocompatibility, which was difficult to accomplish in ancient times (Arun, 2021).

Moreover, in ancient times, the right to health services was usually reserved for rich persons, as materials were expensive (gold, silver, ivory), so only the privileged had access to treatments and procedures, no matter how rudimentary they were at that time. In modern times, dental implants as generic health services are accessible for everyone, but potentially not affordable for a significant part of the world's population (Alghamdi, 2020). Tooth loss represents a true global health issue, and it is a burden to society, from an economical point of view (Righolt, 2015). The dental implant market is characterized by a constant increasing trend, and it is estimated that it will reach the value of 13 billion dollars by 2023 (Alghamdi, 2020). This trend will be maintained, since the world overall population is aging, as the number of elderly persons is increasing rapidly (Christensen, 2009). Partial or complete loss of natural teeth is generally correlated with an increased age, especially in associations with diseases like obesity, diabetes mellitus, osteoporosis, with various medication, which may affect the bone regeneration process around the dental implants (Volponi, 2018). Interdisciplinarity is the key element in our time, so mixed teams of scientists put all their efforts in finding efficient and durable dental implants.

Ancient Period

The first documented attempts of dental replantation and transplantation are found in Allen's report, which was published in London in 1687 (Kawahara, 2008; Allen, 1687). These attempts date back as early as 3000-2000 BC, during the ancient Egyptian and Chinese civilizations. Being limited by the available materials and technology, they mainly had two basic approaches: in the site of the missing tooth either add a simple replacement at gingiva level, secured with metal wires to the remaining teeth situated on the left and right sides, or place an implant directly into the oral tissue (the very beginning of oral implantology).

Both Egyptians and Phoenicians used ligature wires (usually made of gold) to stabilize teeth in position, using either sculpted ivory, metal, or animal teeth (Bremner, 1954; Coleman, 1970). Obviously, gold and ivory were expensive resources, so they were used only by rich people, and teeth were likely used for less functional and more aesthetic purposes. Unless there is a strong connection between the jawbone and the replacement tooth, which would hold it in place and assure stability, it is unlikely that the replacement would take over the entire functionality of the former tooth, given the occlusal forces that would impose a significant level of stress over it. Chinese early dentists also used carved bamboo pegs as replacements. Still, all these materials were not biologically compatible, therefore all attempts probably faced early failures (Abraham, 2014). Also, early dental implants were most likely placed post-mortem, for religious or aesthetic reasons, as the pain suffered during and after the procedure would have been extreme. This is probably the case of an Egyptian king who had a copper peg that had been hammered into his upper jawbone (around 1000 BC), or the Celt discovered in France who presented a false iron tooth (around 300 BC) (Kawahara, 2008; Atilla, 1993).

Written recommendations regarding early implantology procedures are found both in Hippocrates and Celsus works. Around 5th century BC, Hippocrates described the use of gold or silk threads to put back in place teeth lost from injured mandibles, connecting them to the gums or to the remaining fixed teeth (Rodriguez, 2002). In the 1st century AD, Cornelius Celsus wrote "De Medicina", and described the possibility to replace missing teeth by placing other ones taken from living persons or from cadavers (Pasqualini, 2009).

There is evidence of implants placed during the lifetime of early patients that restored the functionality and aesthetics of the missing teeth with an unprecedent success. Around 600 AD, Mayans used seashells to develop dental implants as replacements for three missing mandibular incisors. The shells were processed as to mimic the shape and structure of the teeth. This discovery was made in 1931 by Dr. Wilson Popenoe and his wife Dorothy Popenoe. But it was not until the '70s that the full impact of this discovery would be unveiled: radiograph investigations indicated the presence of compact bone around these primitive dental implants, just like the bone that develops around modern blade implants (Abraham, 2014; Asbell, 1988; Anjard, 1981) This proves that osteogenesis was present around the three implanted teeth which were probably very stable and had been inserted with a technique similar with the current ones. The X-ray investigations also suggested that this mandibular fragment belonged to a 20-year-old woman (Pasqualini, 2009). Therefore, seashells acted like natural biomaterials that restored the ability of that person to eat and carry a relative normal life. From that period, archaeologists also discovered a stone implant that dated from around 800 AD, placed in the mandible of a Honduran early patient (Kawahara, 2008; Ring, 1995).

The Middle Ages

This period is mostly characterized by written recommendations and procedures' description is various medical books. Artifacts that confirm the real practice of these procedures have not been found so far.

According to Andrews R, the Arab physician Abulcasis (936–1013) wrote extensive chapters regarding dental surgery in his work "Kitab al Tasrif" dedicated to surgery and recommended the replacement of missing teeth with either natural or artificial teeth, secured with gold ligatures inserted through the gingiva (Andrews, 1893). Similar procedures concerning tooth replantation are described by Guy de Chauliac (1300–1367), in 1363 in "Chirurgia Magna", chapter 25 (Nunziante, 1968), Michele Savonarola (1384–1461) (Casotti, 1955) and Nicolò Falcucci (d. 1412) (Zampetti, 2005). The later two suggested linen, silk, or simple metal ligatures for keeping the replacement teeth in place (Pasqualini, 2009).

The Scientific Revolution

During the ancient period and in the following centuries, early dental implants discovered in the jaws of unearthed skulls were made from various materials, like wood, metal, rare gems such as jade, ivory, oxen bone or shells. But it was also common, especially in Europe, between the 1500s until the beginning of the 1800s, to use animal teeth (heteroplastic implant) or human teeth (homoplastic implant),

however the rejection rate would have been huge, due to infections that may even turn out fatal for that patient. Besides local infections of the gingiva associated to the phenomenon of foreign body rejection, there was a risk of secondary infections, like tuberculosis or syphilis (Dahle, 1990; Block, 2018).

Pierre Fauchard, considered the father of modern dentistry, wrote in his magnificent work "Chirurgien-dentiste ou Traité des dents", about replantation of avulsed teeth and also about transplantation of teeth from one person to another, and keep them in place with gold, silver or linen threads that would be maintained until stabilization (Spielman, 2007; Guerini, 1976). Human teeth were commonly bought from resurrectionists. They obtained them either from donors who had to sell their healthy teeth (usually poor people), or they used to steel them from corpses during wars or directly by robbing graves (Abraham, 2014; Asbell 1988 2). Before the 1800s, historical sources describe the documents made by of Dr. John Hunter, who performed extensive observations regarding the anatomy of mouth and jaw, following his direct work with resurrectionists (Colyer, 1920; Abraham, 2014). Among his scientific preoccupations, teeth transplants played a special role: he suggested that teeth which are not fully developed may be transplanted from one human to another. He even performed an experiment by implanting an incompletely developed tooth within the comb of a rooster and documented its evolution, which was truly surprising. The blood vessel of the rooster extended and grew into the living pulp of the tooth; thus, the tooth was in the end strongly embedded to the comb of the rooster (Ring, 1985; Asbell, 1988).

Implantation in dentistry concerned not only missing teeth, but also aimed to repair various defects of the cleft palate. The first evidence dates back to 1565, as Petronius attempted to use a gold plate to replace missing portion of the cleft palate (Hinds, 1979; Brettle, 1970). In 1579, the famous French physician Ambrose Pare also recommended plates of gold or silver for filling cavities in the cleft palate, on the condition to be thick as a French crown and a little larger than the cavity itself (Rajput, 2016). In the same period, Gabriel Fallopius (1523–1562), an Italian physician from Padua, recommended gold plates as replacements for any skull defects (cranioplasty) (Sanan, 1997; Aciduman, 2007). Gold was already used since ancient times in Incan or European civilizations, as it was characterized by malleability, and so was silver (Reeves, 1950; Sanan, 1997). But, besides the fact that these are highly valuable metals, expensive and clearly affordable only for rich persons, many important figures like Fallopius, Pierre Franco or Ambroise Pare, considered that these metals could be stolen by the physicians, instead of using them for the patient (Reeves, 1950; Sanan, 1997).

The post-scientific revolution period came with the early development of modern surgery, proper medical documentation under the form of scientific papers, early data about sterilization and disinfection (Kawahara, 2008). Until then, the main reason for dental implant failure was clearly the rejection of the foreign element by the human body. So, scientists began to orient towards other materials, like gold and alloy, porcelain, or platinum to develop new implants. Dr. Maggiolo J, a French dentist, laid the path of modern implantology in 1809, with his reference book "*Le Manuel de l'Art du Dentiste*". He was the first person to describe a modern technique based on an

implant made of 18-karat gold alloy, with three branches that would penetrate the jawbone, and a porcelain crown as a superstructure. The gold tube was placed into a fresh extraction site, and then the site was allowed to heal naturally. The crown was added afterwards, but the whole procedure failed, as the patient experienced extensive inflammation at the gingiva level (Abraham, 2014; Maggiolo, 1809). In fact, gold alloy was not a biocompatible material, also containing copper, which was cytotoxic. With the technology available at that time, Maggiolo had no possibility to shape a metal structure that would fit perfectly in the patient's socket, nor to perform follow-up checks regarding any wall fractures, or possible apical granulomas. Nonetheless, the lack of anaesthetics and anti-inflammatory agents contributed to the final failure of his procedure. It was not until the late 19th century that anaesthetics delivered via inhalation and various antiseptic practices would emerge in the medical field, thus increasing the chances of successful procedures (Harris, 2014).

Still, failures motivated scientists to continue the research for the ideal material that would not be rejected by the jawbone. Both Znamensky and Hillscher, in 1891, used implants made of porcelain completed with gutta percha (Znamensky, 1891; Hillscher, 1891), or porcelain embedded with a platinum disk; Scholl created a root-form porcelain implant designed with a corrugated structure, that would incorporate a wire meant to ensure a connection with the original tooth (Rajput, 2016; Ring, 1995); Payne also used gutta percha to fill in gold plated tin capsules (Payne, 1902), while Greenfield attempted to insert endosseous implants composed by hollow latticed iridio-platinum cylinders (Greenfield, 1913). Often, failures were encountered, as materials like gold or lead devices, corrugated porcelain, iridium tubes or silver capsules, needed to fuse into the bone and not to be rejected by the body (this process is known as osseointegration - a direct contact between the implant and bone, analysed at light microscopic level) (Block, 2018; Shulman, 1985; Shulman 1995).

Modern times

Early in the 20th century, physicians concluded that gold had low complication rates, but it was too expensive to use, and not strong enough to maintain its shape and provide adequate results; silver was taken into account as a replacement, as it was not expensive, it was easy to shape, but it was also found too soft and it was responsible of the skin discoloration in the surrounding areas, due to oxidation (Sanan, 1997).

A breakthrough step was taken in 1930 by Alvin and Moses Stock, two brothers who studied Vitallium, a new material previously used in hip bone implants, and created the first biocompatible implant based on a cobalt-chromium-molybdenum alloy, which was the first endosteal implant placed successfully into the jawbone. Another innovative element was also the shape of the implant designed in a "screw" style (Kawahara, 2008; Linkow, 1991). Eight years later, Adams P.B. successfully patented an endosseous cylindrical implant, with a smooth gingival collar, internal and external threading, and healing abutment (Arun, 2021; Block, 2018). The new implant's spiral design created by the Stock brothers was improved by Raphael Chercheve, who added burs to ease the insertion of the implant and thus to obtain the best fit.

The first attempt of a subperiosteal implant that sits on top of the bone rather than aiming for osseointegration, was performed by Dahl in 1940, after M. Formiggini and F. Zepponi created a spiral post–style implant fabricated from stainless steel (Rajput, 2016). Dahl introduced the concept of flat abutments and screws, that lay over the crest from the alveolar ridge (Linkow, 1991), which was later on perfected by Gershkoff and Goldberg in 1948, who created a cobalt-chromium-molybdenum implant that included the external oblique ridge (Goldberg, 1949).

It was not until 1952 that the foundation of modern oral implantology has been laid, through an accidental observation. Dr. Per-Ingvar Branemark was an orthopaedic surgeon and also a research professor. While studying the bone healing and regeneration processes, he conducted an interesting experiment on rabbits, regarding the microcirculation of blood in hard tissues, after placing titanium chambers in their femurs (Pal, 2015; Branemark, 1969). At the end of the experiment, he was unable to remove the titanium pieces, as they were fully embedded in the bone. Noticing that titanium had completely fused with the bone of the rabbits, he defined the term osseintegration to describe this unique interface between metal and bone and extended its use in dental implants applications. Also, titanium seemed to be resistant to fracturing, as if a fracture occurred, through further experiments, it was always between bone and bone, and never between the bone and the implant (Pal, 2015; Branemark, 1985). The discovery of titanium implants represented the significant breakthrough in the dental industry, which is still oriented nowadays in this same direction.

In early 1960s, Branemark and his team designed titanium screws and implanted them in several dogs' jawbones. About four months later, the results indicated that all the titanium screws were firmly attached to the bone. The strength of this connection was proved by suspending in the air dogs weighting around 20-25 kg, after tying one single implant with a strong metallic wire (Pal, 2015). Five years later, after further experimentation in this domain, a human volunteer, with congenitally missing teeth and misaligned teeth, which led to jaw and chin deformities, received four titanium dental implants (Adell, 1981; Branemark, 1983). Crowns were inserted over the screws, after a six-months period of healing in which the titanium implants fused to the mandible. The patient used the implants for the following 40 years (Branemark, 1977). As it was later proved, dental osseointegration achieved very low infection rates, likely due to the gingival tissue (Hoellwarth, 2022).

With these attempts, the first phase in the development of modern oral implantology had been set in place, with pioneering research and unique clinical procedures. The second phase concerned systematic and fundamental research, as well as planned clinical applications. The first criteria regarding successful implant dentistry were issues in 1978, with the Dental Implant Consensus Conference (Rajput, 2016), and in 1982, after the Toronto Conference on Osseointegration in Clinical Dentistry (Abraham, 2014). In the meantime, progress was visible from the technological point of view. New types of implants emerged: a hollow implant with a threaded piece strategically placed in it, which helped in engaging the bone; implants with hydroxyapatite coating (Arun, 2021); implants with a titanium surface spray designed to improve the interface surface area, and enriched with an intra-mobile detail within it, to replicate the mobility of natural teeth (Sullivan, 2001); or the implant with specific

plasma-sprayed cylinders and screws that are designed to be placed in a single-stage procedure (Pal, 2015). The third phase regroups clinical controls, randomized studies, as well as extended clinical applications, especially after 1993, when Dr. David Scharf published an article in the Journal of Oral and Maxillofacial Implants, showing that dental implants may also be installed in a dental office, not only in an operating room (Rajput, 2016).

In 2002, the American Dental Association published the results of a survey, indicating that dental implants represented the election treatment for missing teeth, identifying thus the fact that dental implants have become an indispensable treatment option in clinical dentistry (Arun, 2021). It was an important milestone in the long thousand-years journey of dental implants, ensuring them the proper place in history, even if this journey will probably never end.

Smart dental implants and IoT – is this the future of oral implantology?

Nowadays, prostheses on dental implants represent an efficient and attractive solution from an aesthetic and functional point of view, for the replacement of missing teeth due to various dental diseases. Although they are designed to be durable, most often they require replacements after 5-7 years, due to inflammation of the gingival tissue, or bone loss caused by occlusal overload (Arciola, 2018). An optimal alternative is LED phototherapy, which promotes the regeneration of different parts of the tooth and gums and reduces microbes over time. Through this procedure, low-level red light is dispersed at certain wavelengths to increase blood flow, accelerate the cell recovery process, increase circulation, and repair damaged tissue (Gokmenoglu, 2014).

Technological advances now allow the combination of the two procedures, by creating an intelligent dental implant, with the following features: it is made of barium titanate (BTO), a material with piezoelectric properties that generates electricity through the natural movements of the oral cavity, such as chewing or brushing; the material resists the colonization of bacteria, generating a negative electrical charge on the implant surface that repels bacteria with negatively charged cell walls; the implant has a built-in LED light source, also powered by electricity generated by BTO, which performs phototherapy and thus protects the gingival tissue, without the need for external sources of electricity (Atul, 2021).

Thus, technology can support patients' oral health through state-of-the-art equipment, modern treatment methods and smart devices. A series of sensors may be embedded in prostheses, offering data regarding the patient's activities, the presence and signs of bruxism, the frequency and accuracy of brushing process. A smart implant may also take initiative in making recommendations: request dental floss when the tartar level is high, suggest a visit to the dental office when problems occur in the oral cavity, or generate a warning when it is not well placed in its socket.

Conclusion

The journey of dental implants began thousand of years ago, paved by intelligent ancient physicians that understood the need of functional and aesthetic dentures, and it reached a point where implants become essential elements in the treatment for missing teeth, with a very high success rate in modern times. Early physicians used a large range of materials in their attempts to functionally replace missing teeth, varying from shells, bamboo, gold or silver ligature wires, ivory, cobalt, chromium, even platinum or iridium. The shape of dental implants also evolved during the years, from simple pegs, tubes connected with wires, stainless steel spirals, screw-type implants, double helical forms or endosseous root forms, all in the search of the best shape that would fill the place of the original missing tooth. All the discoveries during this period of great efforts were important elements that contributed to the functionality and aspect of replacing teeth, however the achievements of the 1950s represented the real foundation of modern implants, especially since the historical context was rather difficult. The use of titanium as artificial root material was a significant step forward, favouring the osseointegration process and offering an impressive stability and durability for the implant. Still, the work does not stop here, there is an obvious need for further progress in this field, in the search of the optimum biocompatible material that would actively stimulate the process of new bone formation.

Scientific progress in many various fields has been embedded in the evolution of dental implants, in order to offer the best option to restore a patient's ability to smile, to talk and to eat properly. The following years will surely provide new materials, innovative shapes, and special coatings for the implants' surface, to offer the patient the very best regarding teeth replacements and treatment options.

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