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HISTORY OF DENTAL IMPLANTOLOGY

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Abstract:
Dental implantology is one of the fastest developing fields of dentistry. However, it has come a long way to become a practice we are familiar with. This article focuses on the milestones in the history of dental implantation since ancient times until modern days. The most outstanding persons and breakthroughs are noted here. A general outline of current state of the art is given and direction of further research in dental implantology is also mentioned.
Key Words: *history, dental implant, alveolar bone, tooth, surgery, osseointegration, graft.*

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INTRODUCTION

People have been facing a challenge of missing teeth since early days of the mankind history. The importance of maintaining dentition at ancient times could not be overestimated because the survival itself depended on it. Various attempts have been made to restore people's lost teeth throughout the course of history, the state of science and technology being the fundamental constituents of the result. Functional rehabilitation was set as a primary goal of dental treatment for centuries. However, in the recent years, increasing aesthetic demands have pushed the clinicians to find the appropriate solutions capable of meeting both functional and aesthetic requirements. This article presents milestones of the long and chequered history of dental implantation, the procedure yielding highly predictable and long-term successful outcomes.

From Ancient Times to the 20th Century

The evidence of substituting lost teeth with available materials can be traced back as far as the ancient civilization of Egypt. J. D. Irish reported of finding a tooth carved from a shell dated approximately to 3500 BC during archaeological excavations [Figure 1]. It was presumably intended to substitute an incisor of the upper jaw [1].

The Moche civilization, which was located within the territory of modern Peru in I-VIII centuries AD, left some evidence of dental implantation. One of the most valuable findings is stored in the Museo del Oro, Lima, Peru. It is a skull with all-natural teeth replaced with 32 artificial ones carved from rose quartz [

Figure 2]. It is unknown whether the surgery was performed during the life or after death; although some signs of bone remodelling found in the alveolar bone can support the first point of view [2].

Figure 1. The tooth carved from a shell (Irish, 2004)

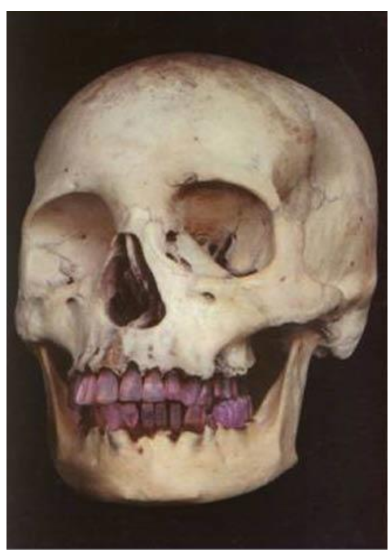

Figure 2. The skull with complete teeth replacement with rose quartz implants (Hildebrand, 2013)

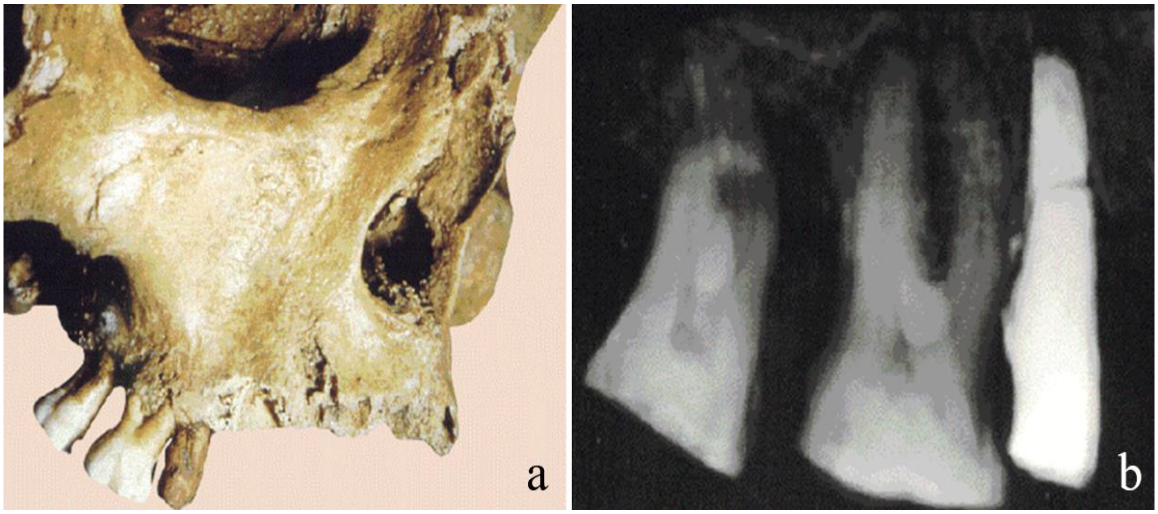

Figure 3. (a) The skull with an implant for the upper premolar (b) The radiograph of the lateral part of the upper jaw (Crubzy, 1998)

E. Crubzy et al. reported of a discovery of a skull in Chantambre (France) with an iron implant in place of the second upper premolar [Figure 3a]. Radioisotope investigation showed the remnants to be approximately 2000 years old. Radiographs revealed perfect osseointegration, i.e., implant surface was in close contact with the adjacent bone [Figure 3b]. Thus, that tooth can be thought to have performed masticatory function for a certain period of time. The success of that operation could be due to a rough surface of the iron that made possible the implant adhesion to the bone [3]. However, in his paper, M. J. Becker raised a doubt of whether that tooth was an implant. In his opinion, it was highly unlikely to reach such precise matching of the implant surface with an alveolar socket at that time. Radiopacity of the tooth similar to that of a metal implant can be explained by impregnation of the tooth with iron oxides from some iron object such as a coin or a nail. Moreover, severe corrosion of a wrought iron implant could have resulted in staining of the adjacent bone but it was not observed. Therefore, the nature of that tooth still remains unclear [4].

There were only few attempts to substitute missing teeth in the Middle Ages. Teeth from dead humans or animals were used with dismal results because of the infection, which followed surgery [5].

J. Hunter (1775) and Owens (1862) transplanted healthy teeth into a cockscomb and observed preserved vitality of the periodontal membrane with blood vessels coming from the adjacent highly vascularized tissues [6]

Pre-osseointegration Era

The development of dental implantation was rapid in the first half of the 20th century. The shape of first dental implants which were presented at that time varied greatly from hollow latticed cylinders and flat-plate-designed to spiral root-looking screws [1]. Special burs were also designed to facilitate the insertion of implants. Both endosseous and subperiostal implants were fixed to the alveolar ridge with screws.

Leonard Linkow was one of the pioneers who brought about a revolution in dental implantology. His name is associated with the blade implant era in the history of dental implantation [1]. He designed several blade implant systems which are still being used [Figure 4] and authored numerous publications on blade-implant integration mechanisms, long-term results, and analyses of failures.

He was firmly of the view that blade implants provide better solution in knife-edge ridges where no other type of implant could be used [8]. Despite a high rate of complications, which have been highlighted some of the blade implants have been functioning for decades after being placed even though the stability of such implants has not reached that of integrated implants [9].

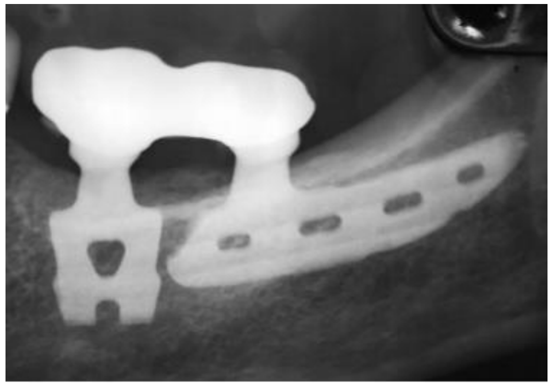

Figure 4. Blade implant designed by Leonard Linkow (Linkow, 2016)

One of the possible ways to substitute missed teeth in people besides placing implants was thought to be via using allogenic teeth obtained from the teeth banks. But this approach faced many challenges, the most important being an immunological response to the allograft. Trying to overcome this obstacle in the 1960s M. Hodosh et al. came up with an idea to create polymer-based dental implants. The original concept of using pure polymethacrylate was further modified by adding 20% inorganic bone. Manufacturing stages included tooth extraction, correcting all imperfections with wax, making an impression, and filling it with a polymer-bone composition. This method allowed for an immediate placement of an implant into the post extraction socket, which was a novel procedure at that time. The use of such implants was advocated by perfect matching to the recipient site and further resorption of the bone component making ingrowth of the periodontal fibres into the implant possible, thus resulting in the fibrous integration. Moreover, a stable gingival connection with an implant surface was shown. The results in the animal models and humans were to a certain extent successful with the implants withstanding the biting forces in baboons over the 8-year period [10].

Fibrous integration and osseointegration are two possible outcomes after the implant placement surgery. Before Brånemark's works, the development of the fibrous tissue around the implant was considered to be a successful result of the surgery as it was thought to be an analogue of the periodontal ligament. However, Brånemark stated that if a fibrous capsule was present that would lead to the implant loss within several years. He proposed an alternative theory of osseointegration which has become a mainstream since then. Thorough and successful studies enabled him to state that osseointegration can be permanently achieved in man. To guarantee such a predictable result he advised to leave the inserted implants unloaded for at least 3-4 months [11]. Decades later, when studying causes of implantation failures, P. Büchler explained them by micromotions of amplitude greater than 0.15 mm which led to the implant instability, a fibrous tissue formation, and a following implant loss [12].

Osseointegration Breakthrough

The major breakthrough in dental implantology is intertwined with the works of a Sweden researcher Per-Ingvar Brånemark, who described a direct bone-to-implant connection when using a commercial-pure titanium screw [13]. To study the blood flow, he placed titanium chambers onto the bone in rabbits. In the end of the recovery period he found bonding of the chamber to be so strong that it seemed quite impossible to detach it. In a series of experiments in rabbits and dogs, he proved that titanium screws incorporate into the bone tissue [Figure 5] [14]. That process was lately termed "osseointegration" and was defined as "a direct structural and functional connection between ordered, living bone, and the surface of a load-bearing implant" [15]. Undoubtedly, that discovery led to the confidence that dental implantology should be introduced into a dental school curriculum [1]. Brånemark elaborated on a system of pure-titanium cylindrical screws called fixtures that marked the beginning of modern dental implantology era [16]. He also proposed a sequence of principal steps for a prosthetic rehabilitation using dental implants [Figure 6] [14].

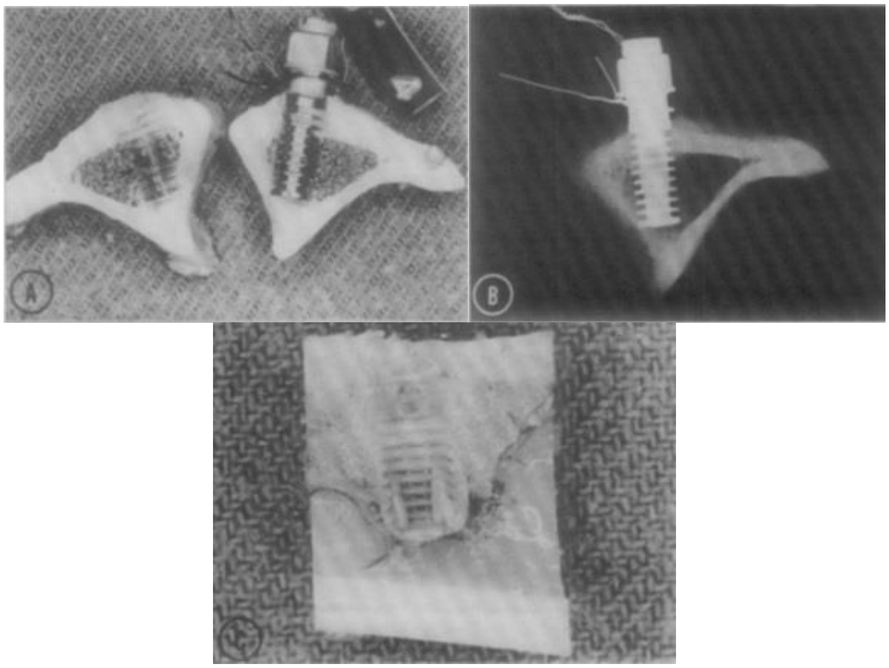

Figure 5. (A-C) An experimental titanium fixture incorporated in the dog's tibia illustrating a new bone formation around the fixture in the medullar cavity (Brånemark, 1983)

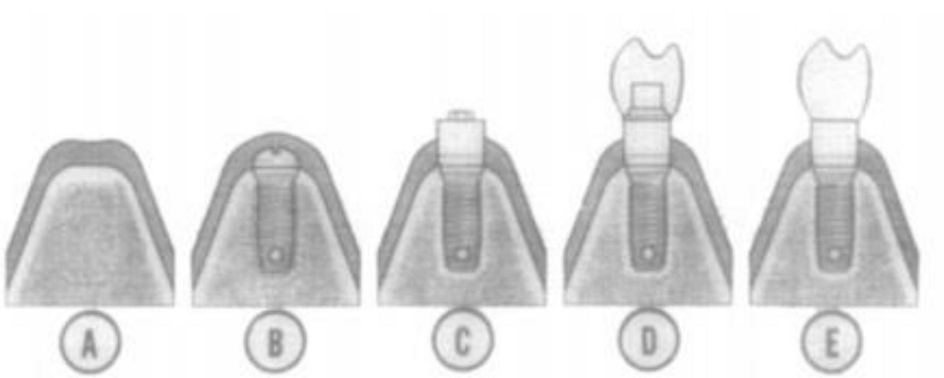

Figure 6. (A-E) An overview of basic steps for anchoring a prosthesis to the osseointegrated jaw bone fixtures (Brånemark, 1983)

In 1993 C. Aparicio et al. were first to show the possibility of the implant placement into the zygomatic bone accompanied with autogenous bone grafting in the cases with severe maxillary defects [17]. In 1997 T. Weischer et al. suggested to place zygomatic implants as supporting structures for further reconstructive procedures in patients with large bony defects after a resection surgery due to the maxillofacial malignant tumours [18]. Conventional zygomatic implants were designed by P.-I. Brånemark and a guideline for their use in patients after a maxillary resection was published in 1998 [19].

In 2004 P. Maló et al. used zygomatic implants for an "all-on-four" rehabilitation technique in edentulous patients [20] and it has been recommended to place zygomatic implants with immediate loading since 2008 [21]. H. Chana et al. analysed retrospective data of 88 patients with zygomatic implants. 95% survival rate was shown over up to 18-year follow-up period. This study proves zygomatic implantation to be an alternative method of treatment in patients with edentulous maxilla and it can be a method of choice especially when compared with extensive surgery on growing the bone tissue in patients with co-morbidity or in those wishing immediate rehabilitation [22].

Core and Surface: Materials and Techniques

The researchers have always had great difficulty in finding a bio-compatible material for implants and although multiple options, such as gold, chromium-cobalt alloy, and stainless steel were suggested no ideal material has been discovered yet [1].

Since Brånemark's discovery of the osseointegration process commercially-pure titanium has been considered to be a material of choice for dental implants [23, 24] due to its biocompatibility, chemical stability, and mechanical properties [25]. The titanium oxide layer covering the surface of the titanium-made implant imparts these qualities to it. However, several studies have shown the increase of serum titanium after total knee replacement surgery and a risk of the cathodic corrosion process accompanied by the formation of reactive oxygen species, which can negatively influence the endothelial cell survival [25].

The structure of an implant surface both on a macro and micro scale is important for successful osseointegration. K. Suzuki et al. measured the volume of the bone adjacent to implants with roughened and smooth surfaces in rabbits and found increased bone volume in the sites with roughened implants [26]. A. Wennerberg et al. also concluded that a removal force was higher in the implants with rough surface [27]. Nowadays several manufacturing methods for roughening implant surfaces are available, such as titanium plasma-spraying, grit-blasting, acid-etching, and anodization [28]. Many coatings may be introduced onto the implants to enhance their biological properties, hydroxyapatite, fluoride, antibiotics, and growth factors being among them [1].

Several materials, such as titanium alloys and ceramics, have been studied in detail as alternative materials for dental implants for the last few years [29].

Titanium alloys, e.g., titanium-4aluminium-6vanadium (Ti_4Al_6V) and titanium-zirconium (TiZr) possess better mechanical properties compared with commercial-pure titanium [29]. The binary alloy is vastly preferable since the corrosion products of vanadium in Ti_4Al_6V can have cytotoxic effect and lead to chromosome damage [30].

There were several attempts to place ceramic implants made of polycrystalline aluminium oxide in the 1960s, but poor mechanical characteristics predisposing to fractures in case of inappropriate loading prevented dentists from using them [23].

Nowadays some disadvantages of titanium have been described in literature, e.g., a dark shadow of gum in patients with thin gingival biotype in the aesthetic areas, probable hypersensitivity to titanium, and unknown body reactions to the corrosion products of titanium. There is a growing interest in the ceramic materials as one of the ways of modern dental implant systems development [31]. Yttrium-stabilized tetragonal zirconium polycrystals are considered ceramics of choice for dental implants [32].

Major Companies

The history of Nobel Biocare Company dates back to 1952 when Brånemark discovered a process of osseointegration. After years of an intensive work with a great number of additional studies, Brånemark and Sweden Company Bofors rallied to establish Nobel Farma, which later became Nobel Biocare. The first tapered and zygomatic implants, CAD/CAM technology, and the "all-on-4" treatment concept are worth mentioning among the innovations introduced by the company [33].

The history of another famous dental implants company began in the middle of the 1950s when a group of Swiss researchers started to investigate different alloys which could be used in dental implants and established a research institute named after its founder Dr. Straumann. The core investigations of the Straumann research group included dental implant materials (such as titanium alloys and pure-ceramic implants), implant surface technologies to decrease healing time, and prosthetic solutions to ease patient's rehabilitation [34].

The Astra Tech implant system, which was designed in Dentsply Sirona Company, is famous for its chemically-modified titanium implant surface. It also proposes solutions for complex clinical cases, e.g., a narrow horizontal alveolar dimension and a sloped alveolar ridge [35]. Dental implants with modified macro-geometry seem to be an optimal solution in cases with a sloped configuration of the alveolar ridge. For instance, Astra Tech Company has presented a dental implant with a scalloped collar allowing to achieve 360-degree bone preservation around it [Figure 7] [36]. Several clinical studies have shown a considerable advantage of the scalloped implants in such cases [8]. However, a systematic review of the Portuguese group has demonstrated no statistically significant difference between a flat-designed collar and a scalloped collar of dental implants [38]. Nevertheless, this is a good point for a further research.

Figure 7. A dental implant with a scalloped collar design (Dentsply Sirona, 2015)

Pre-implant Surgery and Bone Grafting

Pre-prosthetic surgery originated from Germany in the early 1900s. Its birth was associated with a discovery that skin can be used as a transplant to provide wound healing. Skin grafts were used for sulcus deepening at both lingual and buccal sides of the mandible. The numerous disadvantages of this technique (e.g., a scar in the donor site) turned the researchers' attention to mucous grafts. The indications for vestibuloplasty surgery using mucous grafts, the surgical guidelines, and the ultimate goals of the procedure were formulated at that time. As implants were coming into increasingly widespread use in the second half of the 20th century, pre-prosthetic surgery was replaced by pre-implant surgery [39].

The possibility to restore missing teeth with dental implants depends on the available volume of the bone in the surgery site. When implantation is delayed after tooth extraction the initial dimensions of the alveolar bone decrease, thereby leading to little bone remaining for providing necessary implant retention and stability [40]. As dental implantation has become a highly predictable procedure it is a treatment of choice in partially and completely edentulous patient nowadays. Nevertheless, in case of alveolar bone deficiency the success of surgery can be jeopardized. With an increasing drive for optimal aesthetic and functional outcomes of the implant treatment, reconstruction of both soft and hard tissues to create a favourable implant site is considered to be of crucial importance [13].

To overcome this challenge several surgical techniques have been developed, their main goal being to preserve or restore the bone volume for further implantation.

In 1959, L. A. Hurley et al. did the pioneer work in bone regeneration in a series of the experiments on spine fusions in dogs [41]. In 1976 A. H. Melcher noticed that the connective tissue expanding into the alveolar bone defect prevented it from regeneration. It was thought to be due to an inhibitory activity of gingival cells which handicapped the functions of osteoblasts. Hence, he assumed that cells from the adjacent tissues should be prevented from colonizing a bone wound site prior to the osteogenic cells [42]. Later, special barrier membranes were created for the purpose of isolating the alveolar bone and the root surface from gingival connective tissue and epithelium. In 1982, S. Nyman et al. reported of the cementum and the periodontal attachment being restored after applying a membrane into the patient's oral cavity [Figure 8] [43]. This team of researchers conducted a series of studies in which they obtained reproducible results [44]. These works introduced guided bone regeneration (GBR) technique into dentistry.

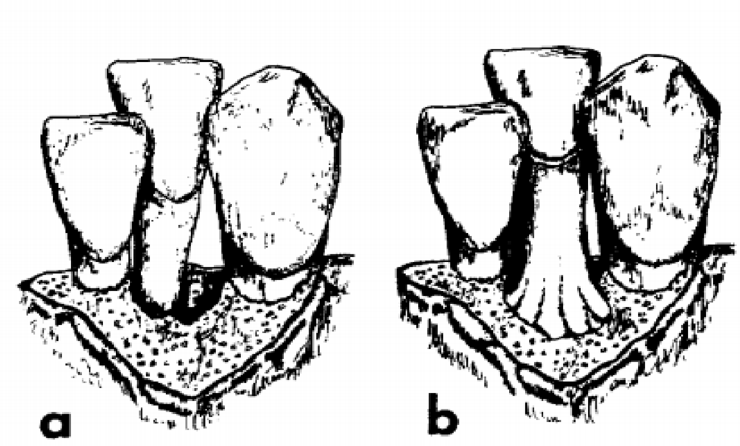

Figure 8. (a) An initial bone defect (b) A membrane covers the root surface (Nyman, 1982)

Extraction socket augmentation is thought to prevent bone resorption and save the bone volume in cases with delayed implantation. However, there are ambiguous data about the efficacy of this method. In 1998 W. Becker reported that such common bone graft materials as bovine bone or demineralized freeze-dried bone being encapsulated by fibrous tissue impeded maturation of the regenerating bone. Nevertheless, in the same study human bone morphogenetic proteins were shown to have a positive effect on bone formation [45]. G. Rasperini found that socket augmentation in the posterior maxilla preserved the alveolar ridge height; therefore, sinus floor elevation was avoided in more cases compared with controls [46].

Another choice for the vertical alveolar ridge restoration is distraction osteogenesis (DO). The idea was initially developed by G. A. Ilizarov in 1975 for general surgery and orthopaedics application. The basic principle of this method is separating a part of the bone to be detached from the underlying bone with a special distractor device [Figure 9]. As blood supply to the mobilised part is maintained new bone formation at the osteotomy site occurs leading to its closure when no further distraction is made [47]. The first attempt at using this technique to increase the alveolar ridge height was made two decades after that by M. S. Block. He performed surgery in dogs and observed radiographic signs of osteogenesis 10 weeks after the distraction was completed [48]. In 2004 M. Chiapasco et al. led efforts to compare the efficacy of DO and GBR in humans. The results proved DO to be more appropriate for large vertical bone defects as the possibility of infection is much lower than in GBR where the membrane may be exposed. Moreover, the bone resorption before implant placement was shown to be significantly lower than in the GBR technique. However, it can be difficult to perform DO at the small sites of 1-2 teeth or at the alveolar ridge where horizontal bone loss has also occurred [49].

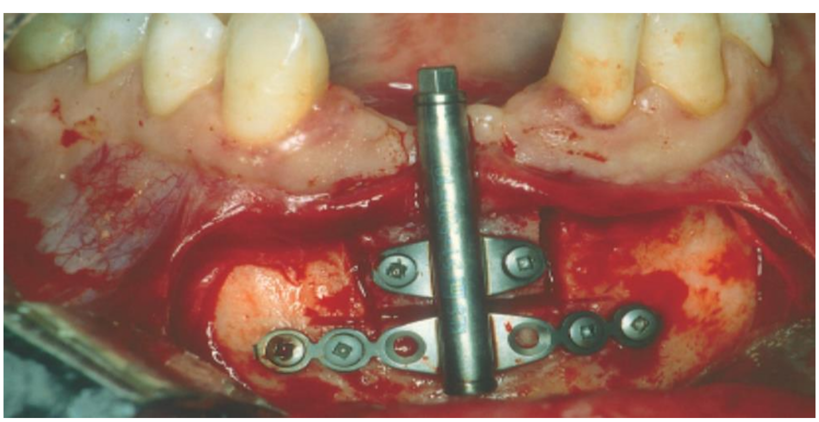

Figure 9. A distraction device fixed in place (Chiapasco, 2004)

A problem of bone deficiency is most common in the posterior maxilla where the alveolar ridge resorption is often accompanied by the sinus pneumatisation. The method of choice in such cases is the maxillary sinus floor elevation or sinus lift. Two surgical procedures, classic lateral antrotomy proposed by Tatum in the 1980s and more conservative crestal approach developed by Summers in 1990s have been well described [Figure 10] [50]. The treatment plan depends on the residual bone volume and its quality [51].

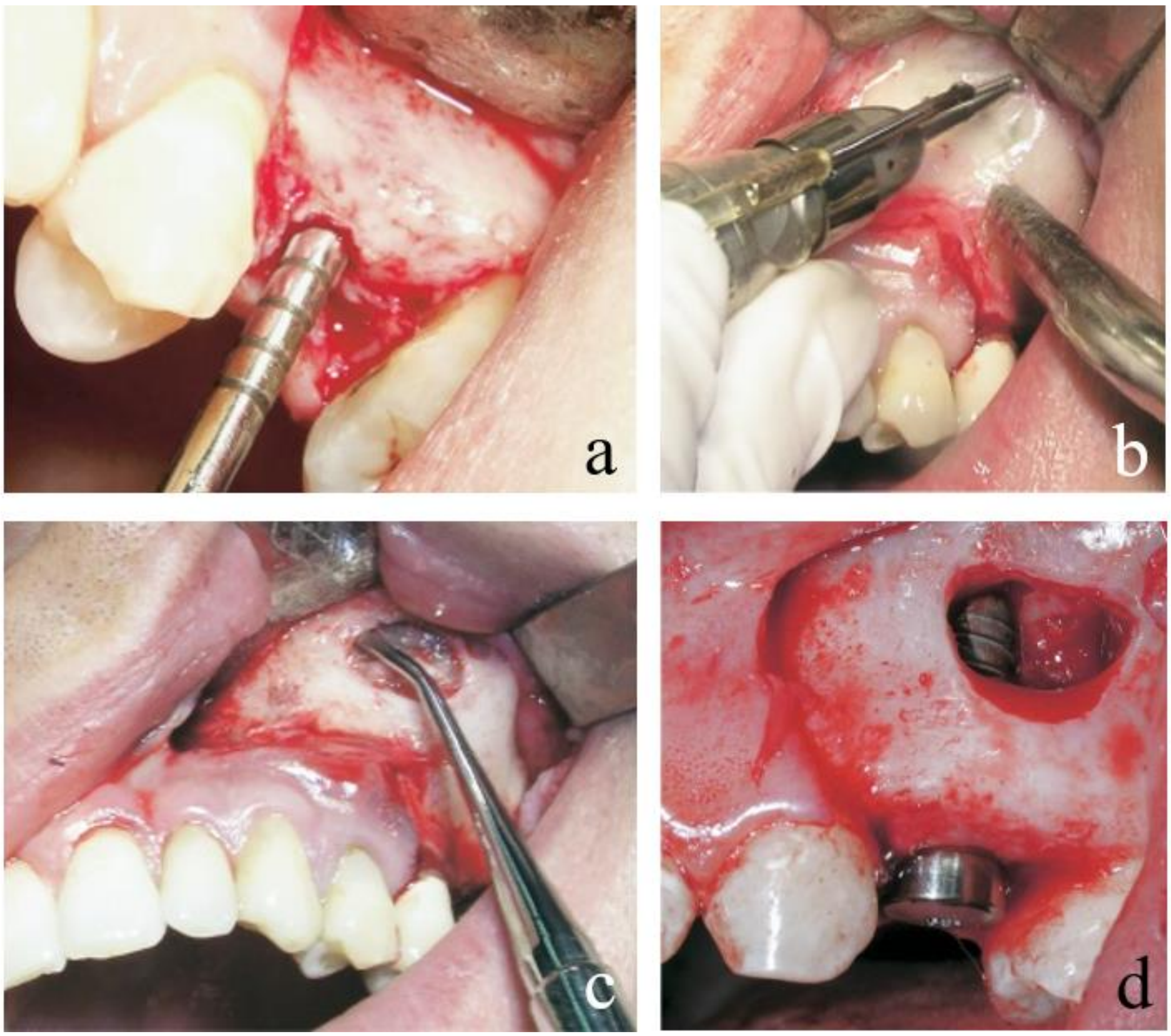

Figure 10. (a) Direct sinus lift (b-d) Indirect sinus lift (Gandhi Y, 2017)

Autogenous cortico-cancellous bone graft is a current gold standard in case of both height and width bone deficiency [39]. The onlay technique described by Curie allows obtaining necessary bone level when severe mandible atrophy is present without inflicting damage on the inferior alveolar nerve [52]. The indications for lateral "onlay" or "inlay" block use include widening a thin alveolar crest. Both techniques require the graft to be perfectly adapted to the recipient site and secured by screws to it. All the gaps should also be filled with a particulate bone graft and covered with a titanium membrane [38]. This technique is highly dependent on the operator's skill due to the importance of ensuring a rigid graft fixation, absence of any micro movements, and a tension-free soft tissue coverage [39].The lack of adequate vascularization of the bone block and low predictability with a reported graft loosening over time [38] make the surgery outcomes less predictable.

The use of contemporary soft-tissue management procedures is aimed at creating a stable and a natural-looking peri-implant tissue environment [39].

Despite recent advantages in hard and soft tissue reconstruction there is still a problem of achieving satisfactory aesthetic results in the anterior segment of jaw when a severe atrophy is present prior to implant placement. Such defects occur when there is a delay between tooth extraction and subsequent implant insertion. Therefore, immediate implant placement was advocated to preserve the structure of the alveolar bone and gingiva. However, only few studies have been done recently to investigate the aesthetic outcomes of immediate implantation directly into the extraction socket [54]. J.C.M. da Rosa has modified a conventionally used immediate dentoalveolar restoration (IDR) technique for using in the anterior sites with unfavourable condition (i.e., with buccal bone defects and thin gingival tissue biotype). He suggested applying a triple graft consisting of a connective tissue layer, cortical and cellular bone harvested from the maxillary tuberosity [Figure 11]. Even with such complex defects present, complete healing and re-establishing of the gingival architecture occurs within 4 months [54].

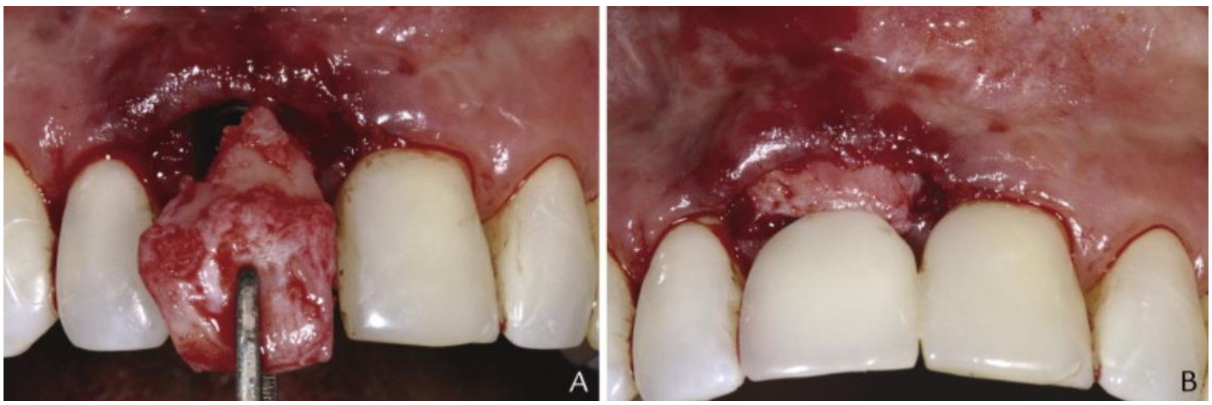

Figure 11. Triple graft placement into the extraction socket (da Rosa, 2014)

CONCLUSIONS

Dental implantology has been developing for centuries to become what we are familiar with today. The current state of art would have been impossible had it not been for the efforts of many scientists, researchers, doctors, and other specialists in dentistry as well as in the other fields. Dental implantology is intimately connected with material science and numerous studies are being done to enhance the characteristics of existing materials and coatings to make better osseointegration and biocompatibility of implants. Various surgical techniques are also being modified and improved to make full rehabilitation possible even in the most difficult cases. Dental implantation is the best treatment choice to substitute missing teeth now and it is most likely to remain such in the future.

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