INTRAOSSEOUS ANCHORAGE OF DENTAL PROSTHESES
An Early 20th Century Contribution

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Abstract: A thorough literature review of root form implants yielded a paucity of information regarding the true pioneers of this discipline. Numerous articles have been written on the history of endosseous implants, although little information is available describing the individuals to whom we attribute the major developments in implant dentistry. This article will present information regarding significant contributors to modern-day implant dentistry. Initially, articles and textbooks printed early in the 20th century were reviewed, and the relevance of implant-related information was ranked based on current concepts. This article highlights four major contributors in implant dentistry: E.J. Greenfield (1913), who developed many of the surgical techniques and principles used today; Alvin Edward Strock (1939), who introduced the first biocompatible material; Per-Ingvar Brånemark (1969), who proved the long-term success of titanium implants; and André Schroeder (1976), who introduced the roughened implant surface.

Throughout history, humankind has appreciated the value of teeth and has sought ways to replace them.[1] However, it is only within the past 200 years that members of the dental and medical professions have made substantial progress in the permanent replacement of missing teeth by intraosseous anchorage of artificial metal fixtures. The first case report dates back to Maggiolo in 1809:[2,3] he described implanting gold roots. Several case reports followed on the implantation of artificial materials to allow tooth replacement by Rogers (1845), Younger (1885), Edmunds (1886), Harris (1886), Bonwill (1895), Edwards (1889), Payne (1898), and Schnol (1905).[2,3] There are many reasons for failure of these early advances; however, perhaps the most significant reason is that in the 19th century iron, gold, lead, and porcelain were used either to replace teeth as artificial roots or as a coating for a replanted or transplanted tooth.[4-7] These materials were not biocompatible, and thus, caused early bone resorption and subsequent implant failure.

By 1913, implantation, transplantation, and replantation were mentioned together in referenced indices. Implantation referred to implanting a synthetic or natural tooth, transplantation described removing a natural tooth from one area or person and placing it in another site or another person, and replantation described removing a tooth and replacing it in the same site. The majority of articles, however, dealt with the replantation and transplantation of natural, not artificial, teeth. Thus, by 1913 significant knowledge existed on the replantation and transplantation of natural teeth, but very little information was available on the placement of artificial implants.[8,9] Greenfield, who graduated in 1899 from the Chicago College of Dental Surgery and practiced in Wichita, Kansas, recognized the limitations of natural tooth implantation and started experimenting with the implantation of artificial hollow-cylinders made of iridoplatinum wire soldered with 24 karat gold. This "hollow basket" design was

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very similar to the design adopted many years later by the Straumann Group (Basel, Switzerland). Greenfield patented his idea in 1909, nearly 100 years ago, and he first reported on this concept in 1911.[10] He then presented a very detailed description of his experience and methods before the Academy of Stomatology in Philadelphia on January 28, 1913. His lecture was published in *Dental Cosmos*, a highly respected dental journal at that time.[11]

The authors feel that the value of Dr. Greenfield's presentation should be more widely recognized because the basic principles and surgical techniques that he used 100 years ago are very similar to those used today. This paper will illuminate Greenfield's work and compare his and other pioneers' significant contributions with the contemporary practice of implant dentistry.

MATERIAL AND METHODS

The authors conducted a Medline® search on the history of endosseous implants (Tufts University, Health Science Library, Ovid Medline 1966-2006, January 5, 2007). The following searches were performed: (1) "history endosseous implant;" (2) "history dental implant;" (3) "dental implant;" and (4) "endosseous implant." Because the body of literature was too extensive for the third and fourth searches, another set of searches limited to review articles was performed and 186 articles were found. A review of these articles resulted in 42 relevant articles about implant history or major implant innovations or contributions. The authors found very limited information on the history of dental implants because the majority of the articles reviewed implant surfaces, shapes, materials, osseointegration, or dental implant treatment planning. Thus, the authors reviewed the references of the obtained articles and searched for articles by Brånemark, Linkow, and Schroeder by hand because these individuals seemed to have influenced implant history significantly (Table 1).

Their early works were obtained and their references reviewed, which unveiled further pertinent information on historical landmarks in implant dentistry. Several articles from the early 20th century were obtained and reviewed, and their importance was ranked based on today's understanding of implant dentistry. As part of the review process, the authors discovered Greenfield's original 1913 article. Because of the detailed implant-related descriptions within the article, the authors began to review the background of knowledge that Greenfield must have had in 1913. As a result, American dental textbooks and the national dental literature indexes from 1890-1925 were reviewed. Also, the orthopedic surgical literature provided the authors with information on several advances in regard to the use of metals in surgery and the knowledge in performing orthopedic surgery around 1913. To provide historical context to Greenfield's surgical procedure, the authors' research team collected literature that pertained to any advances in local anesthesia, sterilization of instruments, aseptic and antiseptic surgical techniques, and the implantation of natural teeth.

Table 1:
Medline Searches Performed and Obtained

Search	Results	After First Search by Hand
1	0	
2	0	
3	162	36
4	24	6

RESULTS

Several review articles have been written regarding the history of endosseous implants;[1-7,12-15] however, none of these articles focuses on those who pioneered the most significant developments in implant dentistry, and how these contributions relate one to another. The authors of this article discuss the following topics and their historical background together with the main contributors of each topic:

- Materials and osseointegration
- Design and loading
- Surgical technique
- Surface

MATERIALS AND OSSEOINTEGRATION

By the end of the 19th century, the groundwork was laid for the advances that were to follow in the field of dental implantology. Sterility of instruments and antiseptic/aseptic principles of wound management already had been developed for general and orthopedic surgery.[16-24] X-rays were discovered in the winter of 1895 in Germany, and their application through radiography quickly followed in the fields of medicine and dentistry in the early months of 1896.[25,26] The introduction of local anesthesia in 1885, by William Halstead, provided dentists with the opportunity to experiment with

the implantation of natural teeth.[17,18,27,28] By 1913, numerous publications on implantation had been written.[8,9,29,30]

It remained for Greenfield to realize the shortcomings of using natural teeth (slow to rapid root resorption) and to embark on clinical research using a metal substitute. It was his hope that because these metal root substitutes would not resorb, they would provide a long-lasting artificial platform, anchored in healthy bone, upon which to build dental crowns and bridges.[10,11,31] It was the chance observation of an orthopedic operation, in which silver wire suture was used, that prompted Greenfield to consider the use of metal in the placement of endosseous dental implants.[11] He envisioned that the metal would be well tolerated by the bone and gingival tissues of the partially edentulous jaws of his patients. The surgical use of silver wire was already well known in the treatment of gynecological problems. Pioneering work by Marion Sims in America and Montague Gosset in England proved that this metal suture was well tolerated by the soft tissues in the successful closure of vesicovaginal fistulas.[32-35] Also, in 1875, Hugh Owens Thomas of Liverpool, England, described the successful use of silver wire to stabilize the reduced fragments of a fractured mandible.[36]

In 1924, Arthur A. Zierold, a surgeon from the University of Minnesota, undertook a research project using dogs, where he compared the tissue reaction to aseptic surgical implantation of several different metals.[37] The objective of his research was to determine whether metal, when implanted into living bone, exerted an influence other than that of any foreign body; and if so, whether this was a property common to many metals or did the reaction vary with each individual metal. Using 63 mature dogs, Zierold implanted the following metals into different skeletal regions: gold, silver, aluminum, zinc, lead, copper, nickel, high carbon steel, stellite, magnesium, iron, and copper aluminum alloy. After a 2- to 6-week healing period, the dogs were sacrificed and histologic specimens obtained. This was one of the first studies that used histologic techniques to help confirm clinical impressions of biocompatibilty.

Though Zierold did not find fusion of bone tissue to any of the metal implant surfaces, it was apparent that different metals exhibited different types and degrees of tissue reactions. Some of his observations were that: (1) gold, aluminum, and stellite were readily tolerated by bone and tended to be encapsulated with fibrous tissue; they were inert materials, unaffected by the living cells and body fluids; (2) silver and lead were slightly less tolerable to bone, but they easily underwent corrosion, and created a greater connective tissue response; (3) zinc corroded easily and caused a slight connective tissue reaction; (4) copper caused definite stimulation of bone, although it underwent slow corrosion; (5) steel and iron definitely inhibited bone regeneration and steel readily underwent corrosion. Zierold speculated that the process of corrosion of the metals in body fluids played a significant role that would explain the different tissue reactions to the various metal implants. Overall, Zierold wrote that his observations coincided with those of a French researcher, Le Fort, whom he quoted: "When the mass is nonseptic, nonirritating by its anatomic location or form or chemical nature, the organism tends to ignore it and the phenomena of defense do not appear. The usual reaction is the encapsulation in a dense wall of fibrous tissue." [37]

Expanding on this research, San Antonio, Texas, surgeons Venable and Stuck published a series of articles from 1936-1938,[38-40] in which they researched corrosion as the main cause for the lack of biocompatibility. The metal that was found to exhibit the least degree of corrosion was vitallium, a mixture of cobalt, chromium, and molybdenum. They stated: "We feel that the criterion in the matter of osteosynthesis with metals is that the metal must be electrically neutral or entirely passive in the presence of body fluids and significantly rigid and strong to do its part mechanically. Surgeons are fortunate in having this metal…."[38]

In 1939, A. E. Strock of the Harvard School of Dental Medicine was the first clinician to use a screw made of vitallium in a human extraction site.[41] This electrically inert material allowed, for the first time in the history of implantation, a reaction-free recipient site after surgical implantation.[42-45] Strock later placed a prosthetic dental crown on this vitallium screw. Unlike Greenfield, who believed that the stability of the implant related to the "locking" of bone in and around

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E. J. Greenfield's seminal 1913 article, "Implantation of Artificial Crown and Bridge Abutments," originally presented before the Academy of Stomatology, and published in *Dental Cosmos.*

the hollow basket design and to the surface of the metal itself, Strock believed that the " principle of the screw" was responsible for clinical stability of the implant.

In 1940, Bothe, Beaton, and Davenport, of Chicago, compared the tissue reactions using several different metals in an animal model (cats) in a continuing effort to expand upon the potential role electrolysis played in the surrounding tissue reaction. Using implants of dissimilar metals surgically placed into the same bone (cat femur), they demonstrated electrical potentials between the implants at 7 months. The following metals were used: cadmium, manganese, aluminum, tin, lead, titanium, copper, stainless steel, and vitallium. Their findings revealed, however, that the electrical potentials, while measurable after 7 months, were not closely correlated with the adjacent tissue reaction. Under their experimental conditions, where electrolytic action should have been favored by adjacent dissimilar metals, each metal retained characteristic individuality of reaction.[46] It was the inclusion of the metal titanium in their research that proved to be of great significance years later. They noted prophetically that: "The response of bone to titanium was as good, if not better, than that to the noncorrosive alloys, in that there was more tendency for the bone to fuse with it…if metallurgical developments of the future make it possible to work it into suitable shapes, it has the strength and hardness necessary for proper support. More experimental work is needed to prove it equal or superior to the noncorrosive alloys as a prosthetic material."[46]

Finally in 1951, Gottlieb S. Leventhal of Philadelphia, strongly endorsed titanium as an ideal metal for use in fixation of bone fractures.[47] He suggested this metal because of its superior characteristics with regard to its tensile and yield strength, weight, resistance to corrosion, ability to be welded and forged, and because it could be machined like stainless steel. Leventhal described what years later Brånemark called "osseointegration" when he placed titanium screws in rat femurs. Leventhal stated: "At the end of 6 weeks, the screws were slightly tighter than when originally put in; at twelve weeks, the screws were more difficult to remove; and at the end of 16 weeks, the screws were so tight that in one specimen the femur was fractured when an attempt was made to remove the screw. Microscopic examinations of the bone structure revealed no reaction to the implants. The trabeculation appeared to be perfectly normal."[47]

In the mid-1950s, Brånemark, an orthopedic surgeon, used titanium to study blood flow in animal research projects. While conducting his research, he found again that the material became solidly embedded in bone. The titanium was almost impossible for him to remove, and he called this phenomenon "osseointegration." He hypothesized that this material might be capable of withstanding occlusal forces, and he began studying the use of titanium for tooth replacements. The shift from vitallium to titanium happened in the era of Linkow's blade implants. The first blade implant was still made out of vitallium; the later designs were all titanium. Brånemark's major contribution toward implant dentistry is his thorough documentation of the long-term success of titanium in animal and human studies before publishing his data in 1969.[48] In 1977, he published guidelines on the successful use of endosseous implants, and, in 1981, his research group published a 15-year follow up of their implant cases. Since then, the use of titanium root-form implants has been considered the state-of-the-art therapy to replace missing teeth.[49,50]

DESIGN AND LOADING

In 1939, a publication by Strock stated: "When a less active material was used, as iridoplatinum by Greenfield, the mechanics involved probably accounts for the lack of success."[41] In other words, the reason Greenfield's hollow-basket implant did not remain in implant dentistry since 1913 was not the bioincompatibility of the material, it was the mechanical loading pattern that decreased Greenfield's success and made the dental profession suspicious of its predictability. Greenfield appeared to be unaware of the mechanical loading principles and their significance for implant success, even though his technique did not involve loading them immediately. The understanding of forces associated with implant dentistry is a topic that has just recently been researched through methods such as finite element analysis and case reports that show bone loss caused by overload.[51,52] During the time of Greenfield, Strock, and Linkow, many of the failures might have been caused, not by the material or the surgical technique that was used, but by early loading or excessive mechanical stress. Greenfield's design of a hollow-basket implant seems unfavorable, as it limits the amount of implant surface area in contact with bone. In addition, he fabricated long-span bridges from canine to molar on those implants. Today, that would be considered overloading.[51]

Brånemark published his landmark papers in a time when the majority of dental implant publications dealt with the subperiosteal implant. Aside from the morbidity of the insertion, the subperiosteal implant functioned. However, many

failures occurred just a few years after placement, likely caused by unphysiologic stress. Brånemark's mechanical approaches were far more conservative than that of many others before and after his research. In his original research paper (1969), he measured the stability of the anchorage and claimed it to be excellent.[48] Brånemark's implant design at that time evolved from the shapes used in orthopedic surgery. He worked in conjunction with an American-trained engineer, Richard Skalak. The first implants that he placed in humans were polished and screw-type in design. Linkow's "blade vent" implant was introduced at about the same time that Brånemark published his initial report.[53] Blade implants became very popular for almost two decades, and a very wide range of different implant shapes appeared. Some of these were screw-type in design. The majority of Linkow's implants were one-piece, meaning that the implant and the abutment were one piece, and had to be immediately loaded. As previously mentioned, research on mechanical loading and associated implant failure was lacking in the 1960s and 1970s. Nevertheless, it can be speculated that, as Greenfield before him, the majority of Linkow's blade implants might have survived long-term, if the loading protocol had been better understood. However, the importance of biomechanics was not understood, and the clinical phenomenon that was encountered around many of the blade implants was a peri-implant radiolucency called fibro-osseous integration.

In 1969, the majority of implant surgeons believed that a fibro-osseous connection was superior to a firm bone-to-implant contact, as it was believed that the fibro-osseous interface had a "shock absorbing capacity" similar to the periodontal ligament around a natural tooth. At that time, advances in implant understanding were hampered by undeveloped histological methods. Beginning in 1976, Schroeder and colleagues became capable of developing proof with their extensive histological research.[54] They demonstrated that the pseudoligament that formed after early or excessive loading of an implant was not the perpendicular orientation of fibers that is found around a natural tooth. Thus, peri-implant radiolucencies failed to show the presumed shock absorbing capacity, and their nature was termed fibro-osseous encapsulation, indicating a pathological rather than an anatomical variation. Because the failure of blade implants and their associated negative reputation most likely is not related to implant material nor implant design, it can be assumed that if appropriate surgical techniques, materials, and loading were to be used, the blade implant would still be a good solution for a patient with a knife-edge ridge. Research regarding overheating bone while placing implants, the importance of a rough surface, immediate loading, and implant overload evolved years after the blade-implant design disappeared. The advantage of the blade implant design is that it frequently allows implant placement without the need for bone augmentation. The most significant disadvantage of blade implants, however, is the need for a more invasive surgery to place the blade. The split-ridge procedure, developed in that era, is technique-sensitive and allows implants to be placed in narrow ridges. It is conceivable that blades could still be an appropriate solution today; however, the design lost most of its credibility during the many years that it was associated with fibro-osseous encapsulation. This is similar to what had happened to Greenfield several years previously.

It is interesting to note that many of the designs initiated by Schroeder and colleagues between 1974 and 1985 (since 1980 the International Team of Oral Implantology [ITI]) "consisted of a hollow-cylinder, one-piece implant."[55] A review article on the development of the ITI® Dental Implant System states: "Other elementary considerations in similar type and designs were described by Greenfield (1913) and Benaim (1959). Greenfield reported satisfactory results with his patented iridoplatinum lattice implant—probably the first clinically applicable endosteal implant."[56] This type of implant design was part of the first series of ITI implants developed by this company. Later the company changed the design from a hollow-cylinder to a screw-type implant modified with holes to allow enhanced bone anchorage. The main goals of the ITI, a team of experts from all over the world, were and still are to do extensive research on biomechanics, design of the implant superstructure, and implant surfaces.[56] The Straumann Group provided the technical research facilities for the ITI. Their ongoing investigations provided implant dentistry with many of the clinical principles, such as loading protocols, that are used today.

SURGICAL TECHNIQUE

One of the major goals of dental implant manufacturers in the past decade has been to simplify the use of implants and to create more practical and logical implant placement techniques. The stepwise use of increasing drill diameters starting from a round bur is not a new concept. Greenfield provided a detailed description of that technique in 1913.[11] He described a distinct and logical method of using a soft-tissue punch, a guide drill, a pilot drill, and a final drill. His guide

trephines had depth markings similar to modern guide drills. Greenfield related the anatomy of the recipient site in width and height to the size of the implant, and suggested using wider diameter implants for molar teeth. Currently, dentists use this rediscovered concept when using implant manufacturers' recommendations for wide body or platform implants on molar teeth. Greenfield downplayed the importance of splinting implants, and he suggested the use of postoperative radiographs to confirm adequate implant position. He specifically emphasized that the osteotomy should have a precise fit (no micromovement) for the hollow cylinder, allowing stability of the artificial root. Today, this concept is called "primary stability." He states that in the initial healing time, "the implant will be held firmly until a sufficient deposit of bone cells has filled the spaces in the root frame. Thus the artificial root becomes solidly embedded in the jaw."[11] Histological methods were not available at that time, but Greenfield's account could be considered an early description of osseointegration. The theory of osseointegration relies on the histological proof of bone-to-implant contact.[54] This method was not applicable in 1913, but at least the idea of the clinical importance of osseointegration appears to date back to Greenfield.

SURFACE

The last significant contribution in implant dentistry was surface roughness. The recognition of the importance of a roughened surface dates back to Schroeder, Sutter, and colleagues (later ITI). Their research was initiated in 1974 and continued to evolve into the ITI-bonefit-implant. The first bonefit-implant was marketed in 1979 and was named the ITI-Type-F implant. This hollow cylinder, one-piece implant had a titanium-plasma sprayed surface. [57]

During that time frame, the ITI research team histologically examined the bone-to-implant interface of the fibro-osseous integration and proved it to be less favorable than osseointegration.[54] In addition, the research team found that by using a roughened surface, the percentage of bone-to-implant contact could be significantly enhanced.[54-58] The roughened surface can be considered another major breakthrough in implant dentistry.[59] Rough surfaces decrease the time required after placement before mechanical loading. Roughened surfaces are believed to increase biocompatibility, and some surfaces claimed to be "osteoinductive." Research on implant surfaces led ITI to change the surface from titanium-plasma sprayed (TPS®) to sand-blasted and acid-etched (SLA®).[56-59] The company that evolved through Brånemark's implant system, Nobel Biocare USA, LLC (Yorba Linda, CA), added the TiUnite® roughened surface to their implants. The innovation of rough-surface implants has paved the way for immediate implant placement after extraction and immediate loading with or without function.

FUTURE

Implant surfaces probably have the greatest potential for enhancement in implant dentistry. By adding proteins on implant surfaces, the bone-to-implant contact may increase further, and healing and loading time may be shortened. In addition, the surfaces may be capable of withstanding bacterial or load challenges to prevent bone breakdown and lessen implant failure.

CONCLUSION

In 1913, E. J. Greenfield, a little known pioneer of the endosseous metal implant, provided the dental profession with many of the basic concepts of the nascent field of implantology. These concepts served as the foundation upon which later clinicians successfully built and raised the standard of patient care. Greenfield's innovative and seminal contributions deserve the appropriate recognition afforded to members of the dental profession who have greatly enhanced the practice of dentistry and the ability to serve patients.

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IMPLANTATION OF ARTIFICIAL CROWN AND BRIDGE ABUTMENTS.

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IN this age of achievement and progress, when it is not at all uncommon for the miraculous to become the actual, when people no longer gasp at the definite accomplishment of ideas which at first glance or consideration are seemingly impossible, it is not at all surprising that prosthetic dentistry should keep pace with the notable achievements in other fields of science.

This great and vitally useful branch of our profession, which is concerned with the mechanical restoration of the organs of mastication, has been both the producing agent and the beneficiary of wonderful developments during the last few years. Consequently our study of the implantation of artificial roots should be considered of the utmost importance by all dentists who are anxious to keep abreast of the times, and should be of intense interest to all who wish to be in the van of progress—in short, to each and every man who desires to be a leader in his particular vocation in his community.

IMPERFECTIONS OF NATURAL TOOTH IMPLANTATION.

For several years the countless attempts to replace natural teeth after extraction have met with only a fair measure of success. Every practicing oral surgeon has probably implanted quite a number of natural teeth, and knows how unsatisfactory this operation is. He finds that five years is a long life for the majority of implanted natural teeth. It is a matter of rather general experience that the implanted natural root fails, viz, simply disappears, because nature absorbs it, just as she does the deciduous tooth.

Like all my brothers in the profession, I have continually been confronted with the very serious problem of just what to do for patients with one tooth missing, or with the posterior teeth all lost. And this problem has been of such intense interest and so vitally important that I have spent every spare moment during the past eight years trying to devise a means of making implantation a permanent operation. I believe my success in this work, the perfection of the process which I shall describe, and the instruments used in it, will be of the same interest to you as they have been to me.

SERIOUS SEARCH FOR A SUBSTITUTE.

Through much study and extensive experimenting, I was early convinced that, even with the most careful work, the implanted tooth could never meet the demands of the profession. Though searching constantly for a substitute, and though having at my beck and call all of the advantages, facilities, and equipment of modern dentistry, my actual discovery of artificial root implantation was somewhat due to chance. One night a few years ago I happened to be present at a very difficult operation. I watched the surgeon reduce a fracture in which he used a silver-wire suture; then and there came the problem-solving query—If a surgeon can use metals

in bone, why cannot a dentist do the same?

THE MISSING LINK IN DENTISTRY.

Inspired by this thought, I set to work with increased energy, and it seems to me that the activity resulting from that chance observation of a surgical operation has produced a process which is perhaps as audacious and revolutionizing in prosthetic dentistry as were the discovery and use of wireless telegraphy, radium, and the X rays in their particular fields of science. For this discovery in actual concrete form is an artificial root that is permanent. I have tested and proved it repeatedly, with continued success, and have demonstrated before clinics in all parts of the country that artificial roots can be put into the human mouth to stay.

This new process of implantation is no less than the making of a few circular incisions in the jaw-bone of an edentulous mouth, inserting properly prepared artificial roots of iridio-platinum, and mounting on each a base or anchorage, to which can be attached a full set of permanent, natural-appearing teeth, capable of rendering as good and efficient service as those endowed by nature at her best.

NO SPLINTS NECESSARY.

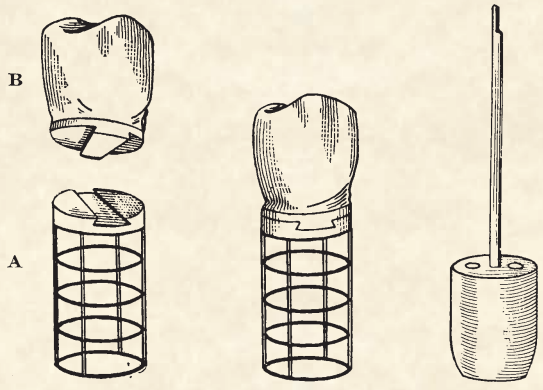
Perhaps the greatest convenience to dentists in this new process is the fact that the splint is unnecessary. For filling the vacancy caused by the loss of a single tooth, what better method could be employed? No splint will be needed, and the adjacent teeth will not have to be mutilated in order to serve as anchorages or abutments; the artificial root eliminates all that. Besides, the mechanical phase of this wonderful process is so utterly simple that it will be readily understood, and proficiency in its use will be quickly acquired by all who desire to use it.

The permanence of the operation is its chief value. At a clinic in Wichita, Kans., Dr. F. O. Hetrick, now president of the National Dental Association, asked the question, "How long will this platinum root last?" And such was and is my confidence in the permanence of this process that I answered honestly, "I do not expect to live long enough to answer that question." And what is more, though the tooth in question was not a spectacular case in any way, it still does not show any signs of deterioration in its enduring qualities.

THE PROCESS AND THE INSTRUMENTS.

The artificial root used for this process is a hollow, latticed cylinder of

Fig. 1. Fig. 2. Fig. 3.



iridio-platinum, No. 24 gage, soldered with 24-karat gold. It is impervious to acids, and does not injure the tissue which grows about it. The disk-shaped cast base with groove or slot (Fig. 1, A), in which the crown attachment (Fig. 1, B) is inserted, is made of 22-karat gold, and is soldered to the metal frame of the root.

Special machinery is necessary for cutting and shaping these roots. Absolute accuracy is essential, for the artificial root must fit exactly the circular incision or socket made for it in the jaw-bone of the patient.

These roots are made in three different sizes or diameters, 3/16, 5/16, and 7/16 of an inch respectively, and are ½ inch in length. As a rule, the 7/16-inch size can be used for supporting a molar, while the two smaller sizes are

employed for bicuspids and anterior teeth. The character of the ridge, however, in which the roots are to be implanted must serve as the ultimate guide in the selection of the proper size of the root to be used in the operation. In a small, narrow ridge the small root is used for a molar as well as a front tooth. The length of the root—½ inch—is ample for any case. Often it will be necessary to shorten the root a little by removing a layer of the crate-like root-frame.

Of course, thorough sterilization of these roots and of the instruments used always precedes the operation of implantation. When everything is ready and the patient has been put under an anesthetic—either general or local—the gum is cleansed with ether and then painted with tincture of iodin. Next the tubular knife (Fig. 3) is employed in the dental engine for removing the gum tissue.

The remainder of the operation is performed with a cylindrically shaped drill or trephine (Fig. 4), which is made in the same three widths as are the roots; likewise the selection of the drill for any particular operation is determined by the character of the ridge in which the trephinement is to be accomplished.

The trephine is first used with the center rod (Fig. 4, A) in place, for the sake of guiding the instrument in position as it starts the socket in the jaw. After the socket is started, the trephine is removed for a moment and the center rod is taken out. Then the excavation is continued to about ⅜ of an inch depth in the alveolar process or bony structure which supports the teeth. In the absence of alveolar process, a socket is trephined in the jawbone to a depth of ¼ inch plus whatever depth is necessary, if any, to permit the tooth-supporting base of the root to be evenly embedded in the gum tissue (Fig. 6).

FIG. 4.

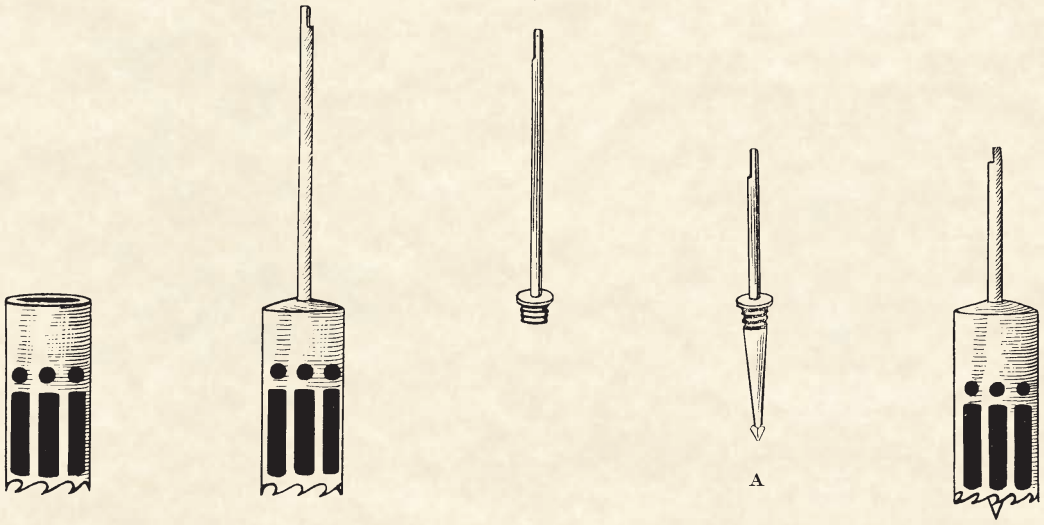


FIG. 5.

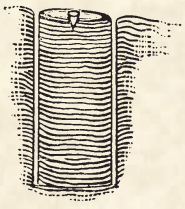
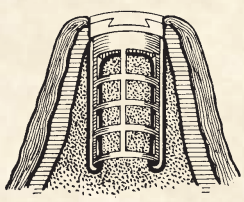


FIG. 6.



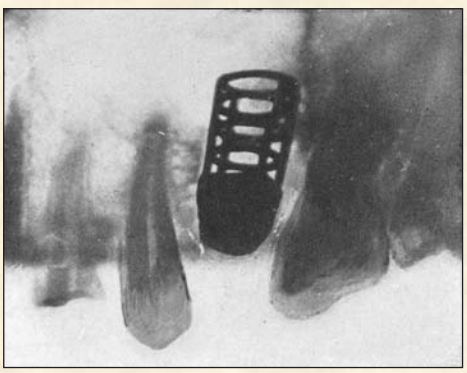
From the above, it will be observed that it is absolutely essential to excavate the root-socket (Fig. 5) to exactly the right depth. Conditions determining this depth may vary, but in any event the attachment for the crown of the root, when in position, must be on a

level with the outer surface of the gum tissue (Fig. 6). It should be noted that a row of holes is punched through the cylindrical wall of the trephine around its center, to serve as a guide to the depth to be attained in trephining.

Thus far the operation should have consumed about five minutes' time. The circular socket in the jaw-bone (Fig. 5) is now finished, and the patient, if he has been subjected to general anesthesia, can be allowed to regain consciousness.

The root-socket should now be filled with bismuth paste, the formula for which is as follows: Bismuth subnitrate

Fig. 7.*



30.0, white wax 5.0, soft paraffin 5.0, vaselin 60.0 parts by weight; mix while boiling. Then the thoroughly sterilized artificial root is placed in position (Fig. 6), *i.e.* sunk down around the bony core or center of the root-socket.

When once in place, the artificial root should not be removed; but if for any reason there is absolute necessity for its removal, care should be taken not to rotate the root as it is taken out, for in doing so, the core of the socket might be fractured or pulled out entirely.

In the course of a week or ten days after operating, sensitiveness has largely abated, and in six weeks' time—rarely longer, the bony tissues of the jaw have united through the latticed root-structure, and a positive anchorage is provided for the attachment of the artificial denture.

*[The radiographs here presented were not shown at the time of the reading of the paper.]

Fig. 8.

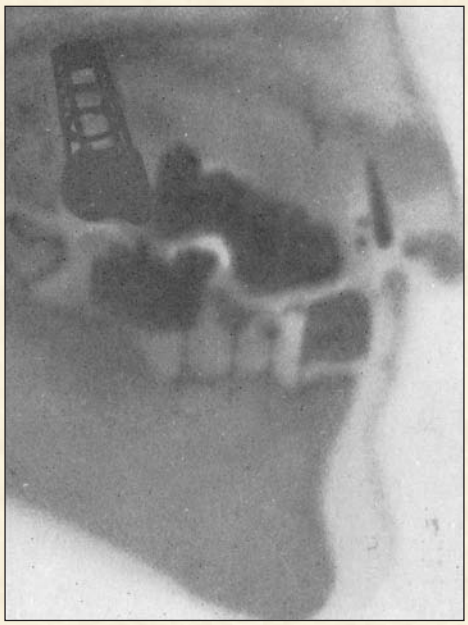


Fig. 9.

HISTOLOGIC REASONS FOR SUCCESS OF OPERATION.

By means of the bony core which the trephine produces in making the incision or root-socket, the artificial root,

after being placed in position, will be held firmly until a sufficient deposit of bone cells has filled the spaces in the root-frame. Thus the artificial root becomes solidly embedded in the jaw.

This bony center of the root-socket is one of the chief factors in the success of this process of implantation. It assures the fit of the artificial root in the socket trephined for it, and an absolutely accurate and certain fit is decidedly essential to permanence and endurance.

Without this core or center, splints would be necessary, also there would be no possibility of operating on an edentulous jaw; but with it, there are practically no limits to the prosthetic appliances available. It is this feature of the process which makes it so inviting and interesting to all members of the profession, especially when the results accomplished are compared with the results of the implantation of natural teeth. The implanted natural tooth fails because of the rarefying inflammation which occurs at the seat of implantation.

The end results can readily be demonstrated by experimentation. It can, also, be proved that in the implanting of new bone in osseous tissue the grafts naturally die, and are gradually replaced by the formation of new bone. In the dead bone or grafts we find a more rapid dissolution, and the defect becomes filled with connective tissue, with latent osteosclerosis or condensation. By analogy, the same process must take place in the implantation of natural teeth.

To go into the minute embryological formation of cartilage and its replacement by bone is a matter too remote for this discussion. Suffice it to state that bone tissue is developed from the mesoblastic layer of the embryo, or the mesoderm, as is all connective tissue. But an understanding of the process of formation of new bone is a necessity in the implantation of artificial teeth, for it is with this knowledge alone that we are able to understand the process, and to gain a clear conception of what we are doing.

When an artificial root is implanted in either jaw, a cellulo-plastic exudation forms around and between the mesh-work of iridio-platinum wire, and is soon converted into granulation tissue, and inasmuch as the constituent cells are derived from bone, they early manifest a bone-forming or osteoblastic function. The periosteum becomes thickened and more vascular, and is slightly loosened for a short distance by an exudation of plasma, which is soon followed by a new deposit of spongy bone on the surface as the result of the irritation.

The granulation tissue from the periosteum unites with that from the bone, forming what might be called the provisional or ensheathing callus. The transformation of this callus into bone starts from the periosteum by the multiplication of the osteoblastic cells and their invasion of the granulation tissue or callus, the cells being derived from the osteogenetic layer of the periosteum.

It will thus be obvious that the continuity of the bone is restored long before the act of repair is completed, and that the end result depends on the ossification of the ensheathing callus. The time necessary for the removal of the clot and the formation of the granulation tissue is about a week or ten days, and new bone formation commences about the first week. By the fourth or sixth week, according to the size of the cavity, the degree of immobilization of the root, and the recuperating power of the individual, the union will be completed, and all tissues consolidated.

APPLICATION IN EDENTULOUS CASES.

In cases of entire loss of the teeth, incisions are made in each jaw at points so selected as to insure sufficient anchorage for the proposed restoration. I have made as many as eight incisions in either jaw for artificial abutments for bridge work.

The danger of these operations may be thought greater, possibly, than the benefits to be derived from them. But such is not the case if attention is given to the prevention of infection by keeping

everything sanitary and sterile—a precaution every dental surgeon should exercise in performing any operation.

CONSTRUCTION OF A BRIDGE.

I have found that a great many dentists are confused as to the setting of a bridge on artificial roots. The impression often prevails that the bridge must be soldered to the caps and then made to slide into the grooves on the roots. This, of course, would be impossible.

One practical way of making a full bridge is as follows: First, a heavy platinum pin is soldered to the gold cap or crown-supporting base of the ordinary artificial root (Fig. 1, B); then the caps are placed in position on the roots. The pins are covered with tin foil so that the plaster will not pull too hard on the roots. Next an impression is taken, and the caps are removed and placed in the impression. Care should be taken to keep them in order. Then the model is poured, the bite taken, and the case mounted on an articulator.

Next, inlay wax is pressed over the post or pin. The tooth is placed in position and the wax is carved as it is to appear when finished in gold. This should be continued until all the teeth are in proper position; then the teeth are removed and the casting is made.

If parts are cast separately, it will be necessary to replace them in position, invest, and solder, care to be taken not to solder the caps to the bridge. Finally the caps should be replaced on the roots, and the bridge cemented in place.

A bridge made in this manner can be made removable by drilling a hole in the pins and castings, threading them, and placing screws in them to hold the bridge.

POSSIBLE LIMITATIONS ARE FEW.

The conditions limiting the success of this process of implantation are decidedly few in number, and inconsequential as to effect. The physical condition of the patient must, of course, be taken into consideration as in any other operation. If the patient's condition is anywhere near normal, little trouble should be encountered in implanting an artificial root.

The nature of the maxilla or the alveolar process in which the intended implantation is to be made also has somewhat to do with the success of the operation. The subsequent solidity of the implanted root depends largely on the amount of the area—the width and depth—of the ridge available for the operation.

This operation must not be placed in the same class as all other implantations, nor should it be anticipated that this process comes to the same end as do all other implantations. No fear is to be entertained that infection will occur. If a solid body is inserted in the maxilla there would be room for infection to set in around it, but in this operation a cage-like, hollow cylinder is inserted in a circular socket in the maxilla. This root is open all the way up, clear to the gum, and the circulation carries away any bacteria which might otherwise be destructive. This is one of the main features in the success of this process of artificial root implantation. If the root were a solid body or even simply perforated, it would be thrown off, as nature would not tolerate it, and there would be room for infection.

Another factor which limits the conditions of failure is the simplicity of the operation, which is neither difficult nor complicated, and can be performed in a few minutes.

Another advantage is the immovability of the root. When once implanted, this artificial root is solid and stationary, the bony core in the center of the socket assuring solidity.

I have implanted both natural teeth and these artificial ones, so I speak from experience when I say that the absorption which takes place after a few years and absolutely destroys implanted natural teeth is entirely avoided by this process, which provides for the anchoring in the jaw of good, solid, imperishable artificial roots.

[See also *Discussion*, as reported under "Proceedings of Societies," this issue.]