

The Impact of Oral Implants — Past and Future, 1966–2042

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A b s t r a c t

This paper traces the history of oral implants, beginning with their early undocumented use in the mid-1960s. Although early experimentation with the Brånemark system of osseointegration was unsuccessful, significant improvements and scrupulous documentation of the 1970s led to their general acceptance. George Zarb spearheaded their introduction into North America and application of the osseointegration technique soon expanded to extra-oral craniofacial prostheses and bone-anchored hearing aids. New possibilities, such as altered surface properties and the use of implants in grafted and irradiated bone are currently being explored, although commercial pressure to introduce new products before they are adequately tested is a cause for concern. The future will see bioactive surfaces and additives that stimulate bone growth. In fact, with the possibility of in vivo growth of new teeth, implants may become unnecessary.

MeSH Key Words: dental implantation/endosseous; dental prosthesis, implant-supported; quality of life

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In the mid-1960s, oral implants were being used in very small numbers. Typical designs were subperiosteal frames, blade vents or transmandibular devices, none of which was properly documented clinically. In general, only poor clinical results had been recorded even though allegedly successful cases were occasionally touted at meetings by the few academic outcasts who used the devices. Not one proper university included dental implants on its curriculum.

Per-Ingvar Brånemark placed his first clinical oral implant in 1965. In the following 5 years, his clinical results were also unacceptably poor, with success rates of about 50%. Brånemark's early results seemed to confirm that foreign materials did not work in the oral cavity for a number of reasons including the risk of infection. The prosthodontic community developed preprosthetic surgery to help edentulous patients who today would be treated with oral implants.

Development during the 1970s

Clinical outcomes for patients with Brånemark's implants clearly improved, not as a result of traditional controlled trial research — in which case we would still have been working with animal models — but in an empir-

ical manner with the simultaneous changing of a great number of parameters. Implants were made wider with some design changes, implant healing time was prolonged and changes were made to the surgical and prosthodontic routines, to mention but a few of these changes. One experimental and one clinical paper were published.^{1,2} The term osseointegration was coined in the latter publication, although the concept was discussed in the former.

Despite indisputable progress, the Brånemark approach was severely criticized by Swedish dentistry, particularly during the first half of the decade. First, osseointegration was not accepted as a clinical achievement and was regarded as impossible by many; a foreign object would never be properly anchored in the bone.³ Second, some patients from the first 5 years of discouraging results had obviously been re-operated by "proper" dentists (Brånemark is a physician) who had noted clear patient discomfort. The parallel with other types of unsuccessful oral implants seemed evident. In fact, this criticism developed into one of the most serious academic disputes we have had in Sweden in the last 50 years. It was finally settled in 1976 when the Swedish Board for Health and Welfare authorized 3 dental professors from universities other than Göteborg to carry

out a clinical review of a selected group of patients treated with osseointegrated implants.⁴

In Switzerland⁵ and Germany⁶ similar developments with bone-anchored implants were well underway. The first generation of hollow-screw osseointegrated implants in Switzerland did not withstand the scrutiny of time because of bone saucerization around these designs. The early German ceramic implants fractured and were subsequently withdrawn from clinical use.⁷ Further development of the Schroeder implants resulted in the Straumann SLA implants (Straumann, Waldenburg, Switzerland) of today, whereas the Schulte's Frialit 1 ceramic implant has been replaced with Dentsply Frialit-2 devices of commercially pure titanium (Dentsply, Woodbridge, Ont.). In North America, progress was initially limited to the Harvard consensus conference of 1978. At this meeting, very liberal criteria for implant success were agreed to, including bone loss of no more than a third of the implant height and implant mobility of up to 1 mm in either direction.⁸ In addition, strange modes for determining implant success were described⁹:

Telephone calls were made to 55 patients.... Eight did not answer, and 34 either had their numbers changed or were no longer there. Thirteen were reached; their summaries follow:

1. One patient's blades were removed 2 years ago
2. One patient had one blade that fell out by itself a few months ago; the rest are loose

All others were doing extremely well and are very, very pleased and happy that they had blades inserted.... One man said that the implant was fine — he buried his wife with it last year.

George Zarb and co-workers¹⁰ had tried to replicate orthopedic surgery — in which polymethyl methacrylate (PMMA) was (and still is) used for implant anchorage — with some success. Their experimental study showed poor results with PMMA-fixated oral implants in dogs (Fig. 1), but they were the first to cite Brånemark's work in the international press.¹⁰

Toronto Replica Study, Toronto Conference and International Publications

Zarb led the first international team to learn the principles of osseointegration (Fig. 2). Five Toronto colleagues, including a surgeon and a radiologist, arrived in Sweden in the late 1970s to be trained in the Brånemark method of implant placement. This course inspired the Toronto replica study of osseointegrated oral implants that commenced in 1979.

Obviously, clinical results achieved at one centre only (Göteborg) are not conclusive; hence the importance of the Toronto study.^{11,12} The long-term Toronto study not only verified the possibilities of osseointegrated implants, but

also developed into one of the world's most important implant databanks.¹³ The longitudinal nature of the Toronto study, in which an implant design was placed by various surgeons then observed by different prosthodontists, enabled study of the impact of the individual clinicians. Not surprisingly, Bryant¹³ demonstrated that the original surgeon and prosthodontist who treated the patient significantly affected the clinical outcome of the implant. These are important findings with implications today when the only concern seems to be the development of new implant hardware marketed in the manner of a new car model.

The Toronto conference of 1982 was another extremely important step for modern implant dentistry. George Zarb took the initiative of inviting representatives of all major dental schools in North America to a conference on osseointegration; 70% of the invited schools decided to participate. Understandably, the general atmosphere at the start of the meeting was quite critical. After all, at the time there were no publications in American journals of any successful attempts to place oral implants anchored in bone. In addition, the Swedish team was unknown internationally. The first day of the meeting was devoted to explaining the concept of osseointegration; the remaining time concentrated on clinical reporting. This meeting was an enormous breakthrough for osseointegrated implants. The proceedings, edited by George Zarb, were published in a separate volume of reprints from the *Journal of Prosthetic Dentistry*.¹⁴

A third important step toward the final acceptance of osseointegration was taken with the publication of *Tissue-Integrated Prostheses: Osseointegration in Clinical Dentistry* in 1985.¹⁵ In 1983, Zarb spent a year as visiting professor in Sweden, where he began work on this book, which has been reprinted in some 30,000 copies and translated into 7 languages. The outline was predominantly the work of George Zarb. Of many chapters, that of Lekholm and Zarb¹⁶ on the classification of jaw bone quality and quantity (Figs. 3, 4) is frequently quoted in the literature to this day. There is little doubt that Zarb was the first international professor to recognize the importance of osseointegration and was doubtless principally responsible for spreading the message about this revolutionary therapy that has had such an impact on dentistry.

Other Clinical Applications of Osseointegration

The first patient with a missing external ear was treated in 1977. The first clinical reports on extraoral, craniofacial implants were published in 1981.^{17,18} This work led to new treatment possibilities. For patients with certain hearing disorders, a bone-anchored hearing aid is attached to a permanent skin-penetrating screw osseointegrated into the temporal bone. Through direct bone conduction, patients' hearing threshold increases considerably and their understanding

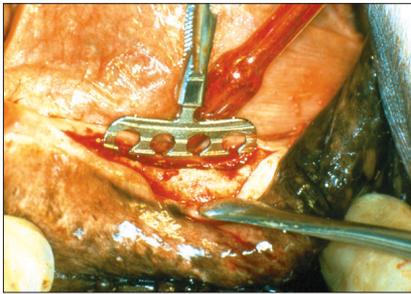


Figure 1: Canine experiments with polymethyl methacrylate-fixed blade-vent implants performed by Zarb and colleagues in Toronto in the late 1970s demonstrated failure of fixation.

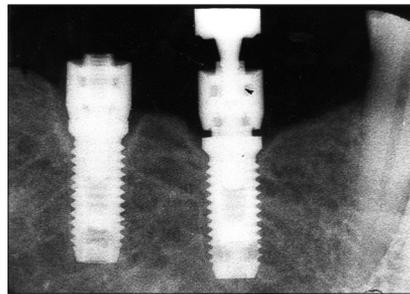


Figure 2: Osseointegrated implants represented a breakthrough in oral implantology, as they made it possible to use foreign materials with a good chance of clinical success.

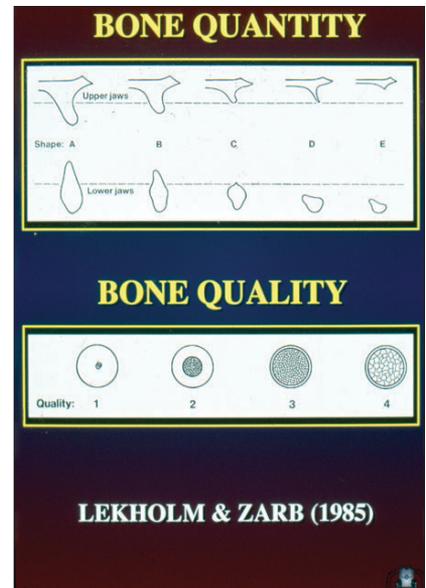


Figure 3: The Lekholm and Zarb¹⁶ index to evaluate bone quality and quantity.

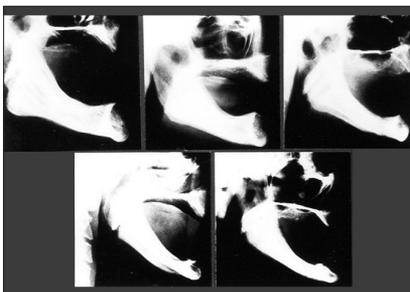


Figure 4: Radiographs demonstrating mandibular bone quantity ranging from Grade A (excellent alveolar processes) to Grade E (almost complete resorption of alveolar processes).

Ss	88	U	4
S1	4	F	4

Figure 5: Typical 4-field table. In this example of a clinical study of 100 implants, 88 met the criteria for success (Ss), 4 were without proper radiograms (survivals, S1), 4 were in one patient who dropped out of the study (U = unaccounted for), 2 had been removed and a further 2 were mobile (absolute failure criterion), 4 failures (F) in all. The advantage of the 4-field table is the possibility of judging implant outcome at a glance.

of speech, particularly in a noisy environment, shows even better improvement. For patients with congenital or acquired facial disorders, 2–4 titanium screws are anchored in the bone to support a silicon episthesis covering the facial defect. This treatment has a profound influence on the patient, enabling a social life despite severe mutilation. Zarb organized the first overseas instructional course in this new technology in Toronto in 1987.

The Importance of Scientific Scrutiny and Controlled Clinical Reporting

According to Zarb,¹⁹ the advent of osseointegration implied a shift from the “pioneering era” to the “scientific era” in implant therapy. However, he also advocated properly controlled clinical studies and did not hesitate to point out some clear weaknesses in retrospective publications from the Brånemark team.¹⁹ In fact, starting with a co-authored publication in 1986,²⁰ Zarb took the initiative to improve the standards of clinical reporting. Many papers were being published without essential data such as proper

criteria for success, information about drop-out rates or any account of the precise number of implants followed up at defined intervals.

In a paper published some years later,²¹ a new model, the 4-field table (Fig. 5), was presented. In simple life tables, very little information about the outcome of an implant is presented. In contrast, the 4-field table with squares for success, survival, drop-outs and failures allows one to

survey the outcome of a clinical study at a glance. Even otherwise excellent implant journals had not realized the problem of poor clinical reporting; therefore, journal editors were invited to a meeting in Toronto that focused on this issue. Since then, the overall standards of clinical reporting have improved. It was pointed out that the best, albeit seldom seen, type of study is the prospective, randomized, controlled clinical investigation. Of good value is the prospective clinical study alone, provided that the report includes a careful description of inclusion and exclusion criteria, the treatment of consecutive patients with consideration of these criteria and detailed information about patient recalls. Further down in the scale, and indeed subject to many biases, is the retrospective report used in the early Göteborg material.

Another topic of particular interest is clinical outcomes in different patient categories, for example, elderly patients. Obviously, elderly patients were treated more frequently with osseointegrated implants than younger individuals. However, it was generally unknown whether clinical results

were as good with the elderly as with younger patients. In 1990, Zarb and Schmitt²² concluded that the literature documenting the longitudinal efficacy of osseointegrated implants in geriatric patients was indeed limited.

Zarb and Schmitt²³ demonstrated that being elderly is not a contraindication to long-term implant survival. This was shown by Bryant,¹³ who reported even better clinical results in the elderly than younger individuals, a fact that was further confirmed in a book edited by Zarb and colleagues.²⁴

Furthermore, Zarb took the initiative to widen the indications for osseointegrated oral implants. The Göteborg clinical material had been almost entirely based on edentulous individuals. At the time of the Toronto conference, only very small numbers of partly edentate patients were treated. Clinical results in partly edentulous patients, including results of implant placement in the posterior parts of the jaw, were published by Zarb and his team in 1987 and 1992.^{25,26} These papers led to wide acceptance of the use of osseointegrated implants for patients other than those totally edentulous.

The Definition of Osseointegration

Osseointegration is a term originally coined by Brånemark.² Although it was clear that osseointegration meant a direct contact between implant and bone tissue, the definition of the term remained unclear. At what level of resolution was the contact direct? Did osseointegration mean 100% bone-to-implant contact around the entire circumference of the implant or was some interfacial soft tissue acceptable? If so, how much soft tissue could border the implant without it losing its osseointegrated state? What was the anchorage mechanism for osseointegration? Furthermore, if a definition of osseointegration were to depend on histologic evidence, how would it be possible to decide whether a clinical implant was osseointegrated?

When George Zarb was visiting professor at the Göteborg University in the early 1990s, these questions were tackled and a new definition resulted: "A process whereby clinically asymptomatic rigid fixation of alloplastic materials is achieved and maintained in bone during functional loading."²⁷ One advantage of this definition is its clinical nature. Having said this, at the time "rigid fixation" depended on a rather crude test with a pair of surgical forceps. Today, the situation is different in that resonance frequency analysis may be used to define a rigid and stable implant.²⁸

The Current Status of Oral Implantology

Oral implants have developed rapidly. After proving the possibility of functioning implants, development has shifted toward esthetics and simplified use. Previous delayed attachment of overlying constructions has been replaced by more or less immediate loading, from the same day to

6 weeks. Today, only when implants are to be placed in bone of poor quality and quantity is a delay of several months before loading recommended. Implants are routinely placed in combination with bone grafts or in previously irradiated bone. Whereas previously most implants were either minimally rough (such as the turned screw) or very rough (such as the plasma-sprayed implant), today the most commonly used implant is moderately roughened, i.e., surface roughness of 1–2 μm (S_a).

However, the developments have not always been positive. Today, new implant designs and surfaces are launched without any attempt at previous clinical testing. Instead, companies present new models at what seems to be an increasing rate. Clinical testing generally starts after the sales launch. The most commonly used implants of today have been clinically documented for only 1–3 years.^{29,30} Whether this development is positive for the patient or mainly for the companies can clearly be disputed.

Expected Developments 2004–2042

Gradually, a better understanding of the importance of surgical and prosthodontic skills will arise from newly designed quality-control tests. Quality-control systems will be used at all major hospitals. Clinicians with significantly poorer than average clinical results will be identified and, if proper explanation is lacking, they will be re-trained.

So-called bioactive implants — devices capable of implant to bone chemical bonding — will become popular. Such implants combine biomechanical and chemical bonding of the surfaces. The advantage of chemical bonding is primarily that it is rapid, in contrast to biomechanical bonding (typical of implants of today), which develops gradually as bone forms and invades implant surface irregularities. In time, doped surfaces containing bone morphogenetic proteins that are gradually released from the surfaces will be developed. Doped surfaces will improve the outcome of implants in grafted bone or where implants might otherwise be unstable, but they will be of little use in the ordinary stabilized implant situation. The development of new ceramic materials will allow the manufacture of implants as well as crowns from ceramics, and this will lead to further enhanced esthetics.

Electrical and electromagnetic treatments will see a revival when we have acquired a greater understanding of the relation between such externally applied signals and cellular function. Ultimately, the traditional bone graft will be replaced with self-made bone tissue, based on the principles of *in vivo* tissue engineering. This development started with preformed grafts and the molding of ossicular bones in the 1970s,^{31,32} but was abandoned because of the high costs at that time. With increasing knowledge about tissue engineering, these problems will be overcome during the coming decades.

We will see the advent of improved diagnostic tools in the form of novel surgical guides. Improved treatment planning will become possible. Currently used techniques such as occlusal papers will be replaced by proper, computerized monitoring of chewing patterns over time.

Towards the latter part of the period our increased knowledge of human genetics will make it possible to stimulate inherent ecto-mesodermal structures to produce new teeth to replace those missing; this will be the final requiem for foreign materials such as oral implants. ♦

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