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Introduction to Dental Implants

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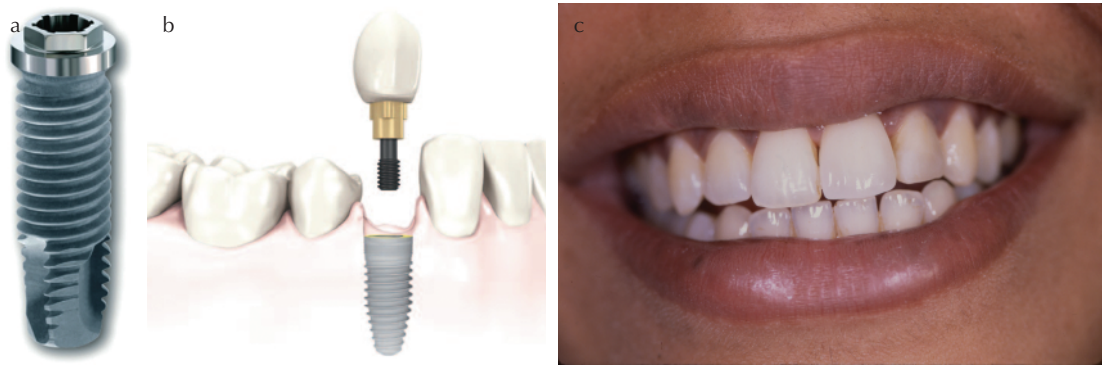
1.1 Introduction

Implantation involves the embedding of a native or foreign tissue or substance within body tissues. The end point of dental implantation is recovered dental function and aesthetics.

It has long been a common refrain in dental practice for patients to express the desire for a “screw-in” tooth replacement. The dream of predictable stable implant prostheses and the current concept of implant “osseointegration” became a reality through the pioneering research of Brånemark and coworkers in Sweden from the mid-1960s, and Schroeder and coworkers in Switzerland from the mid-1970s. (Brånemark et al. 1969, 1977, 1985; Albrektsson et al. 1981; Schroeder et al. 1991, 1996). From a clinical standpoint, research has shown that modern titanium (Ti) endosseous

implants have an overall survival rate of 90–95%.

Beginning in 1952 Brånemark discovered, in the course of vital microscopic studies of blood rheology and bone healing, that titanium (Ti) optical chambers inserted in rabbit bone became firmly attached to the bone and were difficult to remove for reuse; the living bone had “bonded” to the Ti. Later in the 1960s, Brånemark further studied this phenomenon in dogs and, from his perspective as an orthopedic surgeon, contemplated the idea of using Ti implants for artificial joints, bone repair, and edentulism. Brånemark resolved to work primarily on the rehabilitation of edentulism. He coined the term “osseointegration” to describe the stable functional bond between the metal Ti screws and living bone. Brånemark and his team, with meticulous attention to detail, adherence to sound biological principles, and



1.1. (a) Brånemark Mark III self-threading machined implant screw with Ti-Unite® surface and smooth collar (courtesy of Nobel Biocare). (b) Modern implant crown diagram comprising an implant and screw-retained combination abutment-crown (courtesy of Nobel Biocare). (c) Left central incisor implant with metal-ceramic crown.

long-term continuous study, proceeded to develop a standard set of protocols for implant rehabilitation of edentulism. Brånemark et al. (1985) postulated a two-stage surgical approach allowing the submerged implant to heal or integrate for 3–6 months before exposure to the oral environment (Fig. 1.1a,b). Schroeder et al. (1996) in later independent studies postulated a one-stage surgery, a nonsubmerged technique, with transmucosal healing and a shorter healing period of 3–4 months. Otherwise, the techniques were similar in that both used Ti, careful atraumatic site preparation, and prolonged healing.

While Brånemark's vision is now accepted and lauded, it is interesting to note that there was significant controversy and skepticism at the time in his native Sweden regarding this new implant method (Albrektsson and Senneby 2005). In a 2005 commentary, Brånemark suggested that we need to continue to focus on the *“decisive effect of functional load on the healing process and remodeling of bone and marrow”* rather than focus on the *“hardware.”* He further commented that: *“the mouth is a much more important part of the human body than medicine and controlling agencies recognize.”*

1.2 Tooth loss

Consequences of tooth loss on alveolar bone

Bone needs functional stimulation to maintain its form and density. The alveolar bone grows with the developing and erupting teeth. Wolff's Law states that bone remodels (changes its internal and external architecture) in relation to the forces applied. The loss of a tooth and thence loss of functional bone stimulation, leads to bone atrophy and a reduction in alveolar ridge width and height (Tallgren et al. 1980). A removable prosthesis does not stimulate and maintain bone but serves to exacerbate ridge resorption. Ridge resorption of up to 22% vertically and 63% horizontally occurs within 6 months after tooth extraction in otherwise dentate patients (Tan et al. 2012). During the first year following tooth extraction, there is an average ridge width decrease of 25%, and an average 4.0mm height reduction. Implants retain alveolar bone height, but do not completely prevent some alveolar resorption when placed immediately into tooth extraction sites.



1.2. (a) Brånemark implants with attached transmucosal abutments (courtesy of Dr. E. Kim). (b) Brånemark-style reconstruction: mandibular fixed “hybrid” prosthesis supported by five implants (courtesy of Dr. E. Kim).

Demographics of tooth loss

Age is related directly to every indicator of tooth loss: caries, periodontal disease, endodontic problems, and fracture (Meskin et al. 1988; Misch 2007; Jokstad 2009). The average number of lost teeth increases with age (Müller et al. 2007; Zitzmann et al. 2007). There has been a steady increase in the global population that is over 65 years of age. Worldwide, there is a projected increase of over 65 year olds from 550 million in 2000 to 973 million in 2030. Life expectancy is increasing in economically developed countries, and was 85 years in 2001 for the United States (Kinsella 2005). Although the incidence of complete edentulism is on the decline in Europe, the United States, and other economically developed countries, as life expectancy continues to increase, and with continued immigration, the number of people

requiring full dentures in the next 3–5 decades will continue to increase. The total edentulism rate in the U.S. adult population is 10.5% or approximately 18 million people. The reported rate of one and two arch edentulism is 17% or 30 million people, in the United States (Marcus et al. 1996). Global demand for complete denture prostheses is likely to continue increasing (Felton 2009) (Fig. 1.2a,b).

Partial edentulism is even more prevalent in the United States. In 45- to 54-year-old patients, 31.3% have mandibular free-end edentulism, while 13.6% have free-end maxillary edentulism. This partial edentulism rate increases to 35% (mandibular) and 18% (maxillary) in the 55- to 64-year-old age group. The number of U.S. patients with at least one quadrant of posterior teeth missing is more than 44 million (Misch 2007). Up to 70% of the adult U.S. population may be missing at least one tooth. Up until 1995, it is estimated that 1% of patients with an implant indication for tooth loss had been treated with implants. Misch (2007) estimated that a total of 74 million adults in the United States are potential candidates for dental implants. The “baby-boomer” (post-Second World War babies) population in developed countries offers significant growth potential for implant treatment due to high disposable income and longer life expectancy.

Current market research shows that the global dental implant market is expected to grow from \$3.2 billion in 2010 to \$4.2 billion in 2015. Europe is currently the world’s largest market with a 42% market share, and a growth rate of 7%pa, followed by the United States and Japan (Market Reports 2010).

Reasons why implant treatment is increasing

- Implant success has been validated over prolonged periods.
- The population is aging; tooth loss increases with age.

- Traditional restorative dentistry procedures have a limited life span.
- Dentures deliver relatively poor function.
- Tooth loss and removable prostheses generate negative psychology for a patient.
- Dental implant treatment is viewed positively by the public.

1.3 Early dental implants

Historically, numerous attempts have been made to replace lost teeth with artificial substitutes, but with limited success (Ring 1995a, 1995b; Sullivan 2001). Dental implant therapy was initially aimed at the fully edentulous patient or dental invalid who was unable to cope with conventional dentures.

Implant classification

See NIH (1978) and Schroeder et al. (1996).

- *Subperiosteal*: A CoCr casting custom made for an edentulous bony ridge and placed subperiosteally with integral transmucosal posts for denture retention.
- *Endosseous—blade (plate), ramus frame, transosteal or staple, root form, or cylindrical*: These implants are anchored in bone and penetrate the oral mucosa to provide prosthetic anchorage. Linkow (1968) introduced the Ti blade implant. The ramus frame has a tripod of blade-like bone anchorages. Root form designs were introduced in the 1980s by Brånemark et al. (1969), Kirsch and Ackermann (1989) (“intramobil zylinder,” IMZ®), Schulte (1992) (Tübingen), and Schroeder et al. (1991) (“titanium plasma sprayed screw” [TPS]/International Team for Implantology [ITI]) (Fig. 1.3a–d).

Other early implants include:

- *Submucosal implants*: A small “press-stud-like” device within the soft tissue

helping to retain a denture, usually maxillary

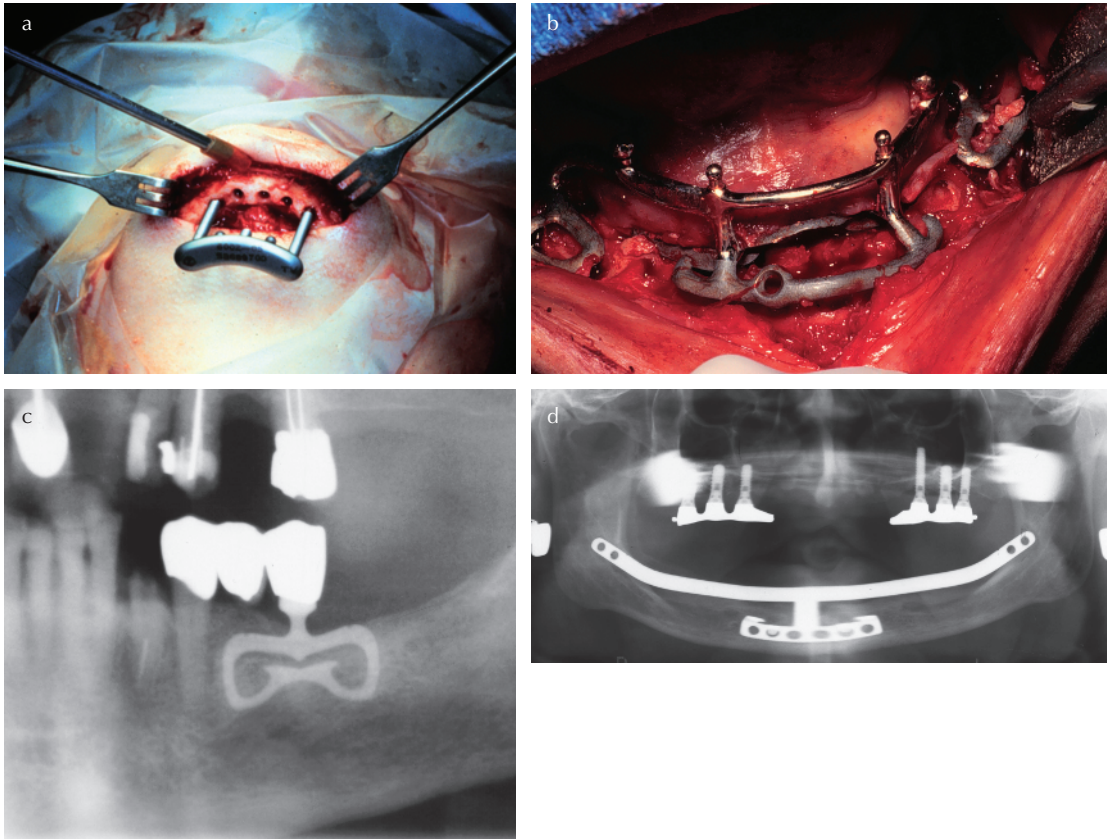
- *Transdental fixation*: A metal implant placed through a tooth and extended into the apical bone, sometimes referred to as endodontic implants

From a practical perspective, blade, subperiosteal, ramus frame, and staple implants have enjoyed modest success. These implants enabled edentulous patients to have a stable anchored lower denture with reasonable function and comfort. Blades have been used as bridge abutments in distal edentulous areas (Kennedy Class I/II RPD cases). However, due to the surgical techniques used and immediate or early loading, there was a high incidence of chronic infection, bone loss and scar tissue envelopment of the implants. They did, however, in many cases, present the only viable alternative to mobile complete or partial dentures, albeit an invasive one.

The use of these early implants was very specialized and tended to be limited to large urban areas with little geographical spread. With the advent of predictable endosseous root-form implants, other implants have virtually disappeared from clinical practice, although they may be encountered occasionally.

Contemporary endosseous root-form implants

Modern dental implants are either cylindrical or tapered threaded screws, or unthreaded press-fit designs. The cylindrical or rotationally symmetrical implant shape allows for controlled and atraumatic osteotomy drilling or site preparation. They are manufactured from commercially pure titanium (CpTi), or titanium alloy (Ti-6Al-4V) with or without surface threads/fins and with or without surface texturing or chemical modification. Implants usually have a screw connection for prosthetic



1.3. (a) External approach surgical procedure for placing a transosteal “staple” implant in the anterior mandible (courtesy of Dr. J.B. Bavitz). (b) Surgical procedure for removal of a subperiosteal implant (courtesy of Dr. J.B. Bavitz). (c) Radiograph of a blade implant (courtesy of Dr. J.B. Bavitz). (d) Ramus frame implant with a tripod of bone support.

abutments, with an anti-rotation feature. This connection enables both surgical insertion of the implant and anchorage of the prosthesis. In the past decade, implant configuration, implant surface modification, and connection design have changed and evolved. There have been repeated attempts to create more stable connections, and surfaces that favor better and more rapid osseointegration, especially in softer bone. The long-term significance of these innovations remains to be seen. Advertising relating to design enhancements is intensive and should be viewed with caution.

Implant treatment

Early implant treatment was largely geared toward complete edentulism, especially of the mandible. Implant therapy progressed to the edentulous maxilla and finally to partial edentulism. The first studies relating to single tooth implants and bridges started to appear in the early 1990s, with increasing emphasis on anchorage stability and aesthetics. The technical challenges and innovative solutions continued to grow as implant popularity spread and demand for implant crown and bridgework increased.

1.4 Pioneering implant research

The ADA Council on Scientific Affairs (ADA 2004) reported a mean survival rate of 95.4% for implants in clinical studies published since 1996. The review included 14 clinical studies covering 10,006 implants and multiple implant designs at follow-up periods of 2–16 years. An average survival rate was judged to be >90% in various clinical scenarios with single units, bridges, and overdentures.

Brånemark group

Brånemark was the pioneer of Ti root-form implants (Sullivan 2001). Beginning in 1952, studies, which have constituted the basis for permanent tissue integration of implants, were performed at the Laboratory for Vital Microscopy, Department of Anatomy, University of Lund, Sweden, also the Laboratory for Experimental Biology, University of Goteborg (since 1960), and at the Institute for Applied Biotech in Goteborg (since 1978). Early studies were vital microscopic studies of blood rheology, bone marrow, and bone healing. Early experiments in rats, rabbits, and dogs showed the phenomenon of bone condensation around the Ti implants when transcutaneous abutments were connected in jawbones. When implants were forcibly removed for examination, the bone fractured but was still adherent to the Ti surfaces. Further work in the development of clinical procedures for the rehabilitation of edentulism was undertaken in dogs. Posterior bridges were made on Ti screw implants 10.0mm long and 4.0mm diameter with a 10-year follow-up showing no significant problems; oral hygiene was provided once or twice per year. On the basis of these animal experiments, which showed stable osseointegration and a favorable interface with mucosal epithelium, human trials began from 1965 onwards. Edentulous subjects were treated with mandibular fixed prostheses supported by four to six screw-type implants. We now know these prostheses as “hybrid” or “fixed

detachable” screw-retained fixed prostheses (FDPs). More than 4000 implants were placed in humans over approximately 10 years. Failed implants were trephined out and studied radiographically, histologically, and with scanning electron microscopy (SEM) and transmission electron microscopy (TEM). Forced mechanical failure was cohesive within bone and not adhesive between bone and the Ti implant surface. An implant survival rate of 96–99% was achieved. A summation of the group’s experimentation with animal and clinical trials was presented at the Toronto Conference on Osseointegration in 1982 along with the eponymous Brånemark implant system (Zarb 1983; Brånemark et al. 1985).

Up to 50 different implant screw designs were tried before settling on the original Brånemark two-stage screw implant, marketed by Nobel Industries circa 1980. The final Brånemark implant or “fixture” for clinical use, after 30 years of laboratory and 20 years of clinical research, was a threaded commercially pure titanium (CPTi) cylindrical screw 3.75mm diameter, 7.0 to 18.0mm long, with a slightly wider collar (neck), and a hole and thread-formers at the apical end. The wider collar was designed to engage the cortical bone of the ridge crest for initial stability, and the apical perforation allowed bone in-growth to resist rotational forces. A transmucosal cylinder or healing abutment was added when the implant was uncovered at second-stage surgery. The original implant design has been extensively modified over the past 30+ years and many variants are now supplied by the commercial group (Nobel Biocare) affiliated with Brånemark’s work. Initially, training in the Brånemark protocol was offered only in Sweden; gradually, other research and training centers were established throughout the world.

Schroeder/ITI, Schulte, and Kirsch groups

In 1975, the International Team for Implantology (ITI), the Schroeder group, in collaboration

with the Straumann Company, demonstrated osseointegration of plasma-sprayed Ti (TPS) implants in monkeys (Albrektsson et al. 1986; Laney 1993; Spiekermann 1995). These ITI implants were designed for a one-stage surgery. Their findings were published in book form in German in 1988, and in English 3 years later (Schroeder et al. 1991, 1996), enabling the affiliated Straumann implant to reach the English-speaking audience and U.S. markets. The Straumann system has become one of the best researched and most popular contemporary implant systems (Jokstad 2009). One implant variant developed by Straumann and ITI was called the “Swiss screw,” which had a TPS surface and integral abutments, and was primarily geared toward overdenture treatment (Babbush et al. 1986).

Another innovative ceramic (Tübingen) implant system, was developed in Germany for immediate postextraction placement (Schulte and Heimke 1976; Schulte et al. 1992). It demonstrated good osseointegration, but had some technical difficulties in the connection of abutments to the implants. The Tübingen system later adopted Ti as the base material (Frialit® II), but maintained the stepped design that was deemed favorable for implantation into tapered tooth sockets, and added some threads (d’Hoedt and Schulte 1989).

Kirsch and Ackermann (1989) (IMZ, Germany) pioneered a cylindrical, rounded, press-fit (no threads) implant with a plasma-sprayed Ti surface (TPS). This implant was unique for having an intramobile element to help dissipate impact forces.

All three alternative press-fit implant designs (ITI, Tübingen/Frialit II, and IMZ) and surfaces (machined CPi, TPS, and ceramic) had documented osseointegration and clinical success (Albrektsson et al. 1986).

1.5 Commercial implant history

According to Jokstad (2009), there are more than 600 implant systems and at least 146

manufacturers globally. Currently, the major implant companies are Nobel Biocare, Straumann, Dentsply, and Biomet-3i.

Implant brands are often a division of major biomedical enterprises with a global reach. Consolidation of the industry seems to be occurring in the West (e.g., Dentsply), but we have yet to experience the influence of developments in Asia on the Western market. It is not unusual for implant companies to change ownership or change branding. Marketing generally seems to override research and development, and in order to select the optimal system for patients, the dental professional must look closely at the ongoing clinical research data of the implant system rather than marketing campaigns for purported benefits that are not proven clinically over the long term (Jokstad 2009). It is important that the implant be serviceable throughout the lifetime of the patient. It is a rather sobering thought for dentists and patients that a treatment with long-term medical devices may be supplied by a company that goes out of business or fails to provide support.

The practicing dentist needs to be familiar with the recent history of implants, as older variants may present in patients for management of problems. There are information websites on implant identification and third-party component suppliers for discontinued implant lines. Occasionally, dental laboratories may be familiar with several systems, and stock components and instruments. Cases involving unfamiliar implant systems should be referred to the original treating dentist or a specialist prosthodontist.

Nobel Biocare (Nobel Bofors/Nobelpharma)

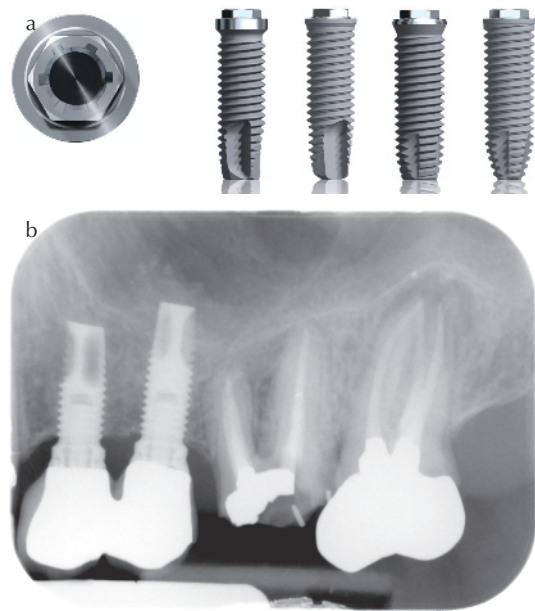
Nobel Biocare is the commercial arm for Brånemark’s pioneering research. In 1965, the first human subject was treated with Ti implant screws and a fixed screw-retained prosthesis for an edentulous lower jaw (Brånemark 2006).

Brånemark noted the potential for mandibular flexure and confined the fixtures to the anterior mandible supporting a fixed cantilevered denture. In 1978, the Swedish Health System approved Ti implants for clinical use. In that same year, the armaments company, Bofors of Sweden (Later, Bofors Nobelpharma, and currently Nobel Biocare) agreed to partner with Brånemark for the commercial development of the implant system. In 1982, the Food and Drug Administration (FDA) approved the use of titanium dental implants in the United States. In 1983, Mats Andersson developed the Procera® method of manufacturing crowns; this technology was acquired by Nobelpharma in 1988.

The classic Brånemark implant was a 3.75-mm diameter, 7.0- to 18.0-mm long, machined CPTi screw with a slightly wider polished collar and an “apical” thread-former. There was an external hex that allowed for surgical placement, to be followed by a screw-retained transmucosal abutment or extension cylinder. The hex became the anti-rotation device for single crowns. Historically, this is the most commonly placed implant, and many other implant companies have used a similar design. The Brånemark implant is the implant with the greatest body of clinical research (Fig. 1.4a,b).

Straumann (ITI/Bonefit®)

The Straumann Biomedical company, a pioneer in orthopedic implants, started work on dental implants in 1974 under the guidance of Dr. F. Straumann, and Professor A. Schroeder of the University of Berne, Switzerland. The early hollow-basket design evolved through various hollow cylinder, solid, press-fit, and screw designs to the current solid screw design. Implants were originally made from Ti, with no threads, a hollow perforated body, and a plasma-sprayed textured Ti surface (TPS). The early one-piece implants were designed



1.4. (a) Modern versions of the original Brånemark implant screw (courtesy of Nobel Biocare). (b) Radiograph of Brånemark implants with joined crowns.

with an integral transmucosal abutment (also seen with blade implants). The later two-piece implants have a flared, beveled and polished, transmucosal collar. This design pioneered the one-stage surgical technique, and favored a more natural emergence profile of crowns. Straumann introduced an internal morse taper (internal connection) for frictional retention and stability of abutments, and later modified it with an internal octagon. In 1980, under the aegis of Dr. Straumann and Professor Schroeder, the International Team for Implantology (ITI) was founded. ITI has become one of the largest independent academic organizations in implant dentistry and the related field of guided tissue regeneration. For more than 30 years, ITI has partnered with Straumann in the development of Straumann implant products (Fig. 1.5a–e) (Buser et al. 1988, 1997; Sutter et al. 1988).



1.5. (a) Straumann implant prototype from 1974 showing hollow basket design and integral transmucosal abutment (courtesy of Straumann). (b, c) Early ITI one-piece and two-piece implants: solid (machined) and hollow (TPS-coated) (courtesy of Straumann). (d) Current solid ITI implant with abutment for a cemented crown (courtesy of Straumann). (e) Radiograph of modern, solid, flared-collar ITI implants (courtesy of Dr. T. Taylor).

Tübingen (Frialit/Friadent-Dentsply)

In 1974, Dr. W. Schulte developed a ceramic implant (Al_2O_3) at the University of Tübingen, Germany. The Tübingen implant was a tapered, stepped, root-form, press-fit design. It was designed for placement into extraction sockets and used a cemented abutment. It was the forerunner of the current Frialit implants, introduced in 1980, which have a similar stepped shape but are made from CpTi and have external threads for initial stability (Dentsply Friadent) (Schulte et al. 1992; Gomez-Roman et al. 1997). The switch to Ti and screw connections overcame the inflexibility of the original design. The Tübingen implant proved the potential of ceramic as a viable implant material (Fig. 1.6).

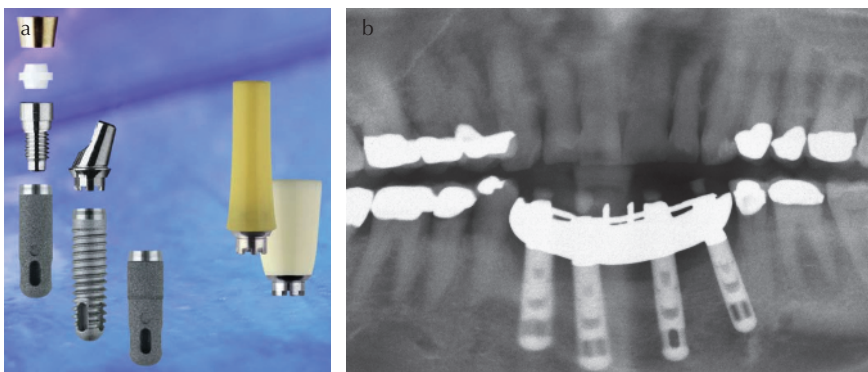
IMZ (Interpore/Dentsply)

A German-designed “intramobil zylinder” (IMZ) implant by Dr. A. Kirsch gained clinical popularity in the 1980s and 1990s (Kirsch and Ackermann 1989). The IMZ was a cylindrical press-fit design made from CpTi, with a plasma-sprayed Ti surface (TPS). It had a polished collar, and introduced the concept of a shock absorber or plastic “intramobile element” to

mitigate functional stress. This intramobile element was later discontinued and an external hex adopted, to accommodate single crowns. Currently, an internal “spline” design is used. To date, over one million IMZ implants have been placed worldwide (Dentsply–Friadent) (Fig. 1.7a,b). More recently, Dr. Kirsch is associated with Camlog implants founded in 1999.



1.6. Tübingen stepped, press-fit ceramic implants (courtesy of Dentsply Implants).



1.7. (a) Modern IMZ implants and components including the nylon intramobile element (courtesy of Dentsply Implants). (b) IMZ implants supporting a screw-retained prosthesis.

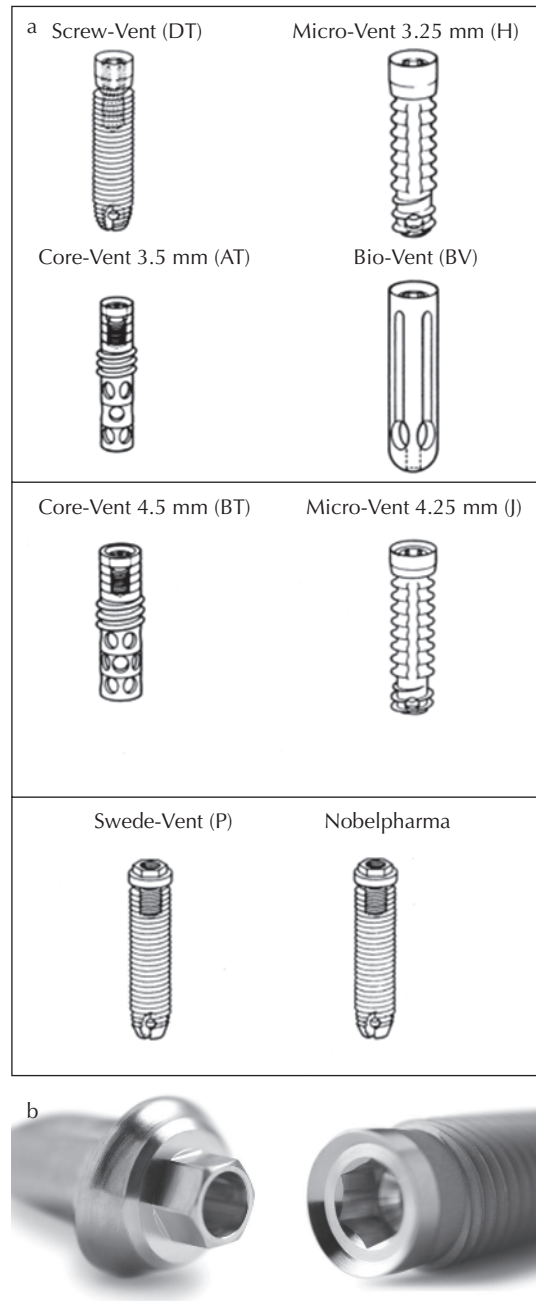
Core-Vent (Paragon/Dentsply/Sulzer/Centerpulse/Zimmer/Implant-Direct-Sybron)

The Core-Vent Corporation in North America was founded by Dr. G. Niznick (Niznick 1985). Core-Vent produced an array of implant designs and obtained numerous design patents. The original Core-Vent implant was a “hollow basket/cylinder” design. It had three threads, a patented internal hex connection, and was made from Ti alloy with a textured, grit-blasted surface (Fig. 1.8a,b). Other designs included a Swede-Vent™ implant in CpTi, similar to Brånemark’s design, and a variant with a patented internal hex connection and peripheral bevel (1983) (Drago and Peterson 2007). A later modification, in 1994, tapered the internal hex walls by 1.5° to give enhanced connection stability and prevent screw loosening, especially for single crowns. Further implant designs featured press-fit with plasma-sprayed hydroxyapatite (HA) coating. Core-Vent (Paragon) implant designs were acquired first by Sulzer Medica (Centerpulse) in 2000, and later by Zimmer in 2003. Zimmer currently market Core-Vent and Sulzer designs (Fig. 1.9).

In 2006 the Niznick Company, Implant Direct, started to produce a line of implants marketed and sold over the Internet. Implant Direct merged with Sybron Implant Solutions in 2011 to form a new company—Implant Direct Sybron International. Sybron had marketed several implant designs, including “Endopore.”

Calcitek (Integral/Omniloc/Sulzer)

Calcitek Integral and Omniloc implants were cylindrical, press-fit implants with a plasma-sprayed hydroxylapatite (HA) coating and several connection designs. Calcitek was a division of Sulzer Medica Inc. (Finger and Guerra 1989, 1992). Calcitek seems to be synonymous with HA coatings within the United States,



1.8. (a) A selection of Core-Vent implant from the 1980s. (b) Proprietary internal hex connection with lead-in bevel in Zimmer Screw Vent implants (courtesy of Zimmer Dental).



1.9. Zimmer Swissplus implant and abutment (courtesy of Zimmer Dental).



1.10. Tri-channel connection design (courtesy of /Nobel Biocare) and Replace™ Tapered Groovy implants (courtesy of Nobel Biocare).

although other companies used the same technology around the same time (Lifecore, Core-Vent, 3i, and Steri-Oss). HA surface coatings were utilized in an attempt to enhance osseointegration speed. There were some problems with the loss of the HA coating (separation of the coating from the Ti substructure) and saucerizing bone loss. This may have had more to do with the HA coating process than the HA material itself. The Albrektsson (1998) review showed unacceptable bone loss with Calcitek HA implants and this led to their withdrawal from the market (Biesbrock and Edgerton 1995; Watson et al. 1999). Ong and Chan (2000) have discussed the risk of HA dissolution. The HA surface process has largely been supplanted by other Ti-textured surface technologies that reportedly enhance osseointegration.

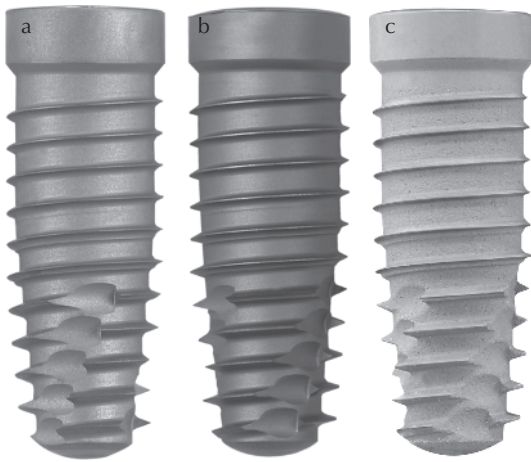
Steri-Oss (Nobel Biocare)

Steri-Oss implants appeared circa 1985 as straight or tapered Ti screws, with an external hex and four color-coded diameters. Surface finishes included acid etching, HA coating and TPS. A second identical line of implants (Replace Select™) had an innovative internal

tri-channel internal connection. This latter design has become the most widely used and favored connection for the restorative dentist due to its simplicity and positive, intuitive clinical handling. Nobel Biocare acquired the system in 1998 and Steri-Oss products were subsumed into the Nobel Biocare implant system (Fig. 1.10).

Implant Innovations International (3i/Biomet-3i)

In 1985, Implant Innovations Inc. (3i) began manufacturing prosthetic components for implants. Later, 3i introduced its own implant, which was similar to the Brånemark design, and gradually produced a complete system of implants. In 1991, the company introduced wide-platform or wide-body implants (5.1 mm, 6.0 mm) with the same-size hex connection as for the standard 4.1 mm implant. It was discovered that when wide-platform implants were restored with narrower diameter abutments, they showed less bone loss than traditional



1.11. (a) Biomet 3i implant with OsseoTite® surface. (b) Biomet 3i implant with NanoTite™ surface. (c) Biomet 3i T3® implant with a combination of coarse and fine surface roughness (courtesy of Biomet 3i).

matched implants and abutments (Lazzara and Porter 2006). This led to the concept of “platform-switching,” which has been incorporated into many modern implant designs. 3i has a unique laser-coded marking system for healing abutments that simplifies data transfer for CAD/CAM laboratory work. 3i are now part of Biomet Inc. (Fig. 1.11a–c).

Astra Tech (Astra-Zeneca/Dentsply Implants)

Astra Tech has produced implants since 1985. They have focused on implants with a proprietary surface coating (TiOBlast™) and a platform-switched design with an internal tapered connection (Al-Nawas et al. 2012). Astra Tech pioneered the use of micro-threads (Hansson 1999) on the collar of their implants with a view to optimizing stress transfer in the crestal bone in order to minimize bone loss. This innovation now appears on many implant brands. Dentsply acquired Astra Tech in 2011 (Fig. 1.12).



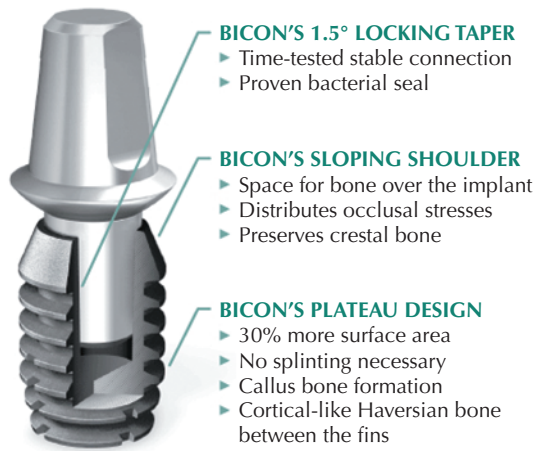
1.12. Astra Tech implants with internal connection (courtesy of Dentsply Implants).

Bicon

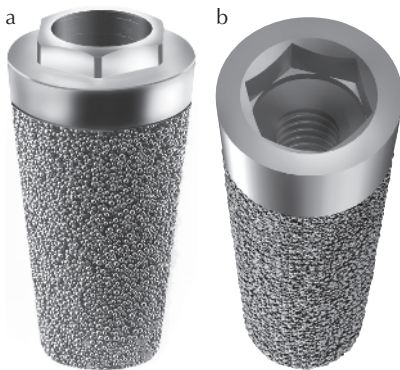
Bicon implants have been available since 1985 (Jokstad 2009). The design is press-fit, with fins rather than smooth walls. Bicon claims the first modern acid-etched surface, a revolutionary tapered locking connection (i.e., retaining screw) system and a reverse bevel collar design. Another significant feature of Bicon implants is their very short implant designs, as little as 5.0 mm long (Fig. 1.13).

Endopore (Sybron)

Endopore produced a unique implant that was a truncated cone, press-fit design geared toward posterior jaw locations (Jokstad 2009). These implants had a unique porous Ti surface that allowed for bone in-growth. The surface was produced with a sintered Ti alloy powder coating. It was claimed that the in-growth of bone into the Ti structure allows for optimum handling of lateral tensile loading forces, as compared with other machined and textured implant surfaces (Fig. 1.14a,b). Endopore



1.13. Bicon implant and friction-fit abutment (courtesy of Bicon Dental Implants).



1.14. Endopore implants with (a) external hex and (b) internal hex connections and sintered Ti surfaces (courtesy of Sybron Implant Direct).

implants have been discontinued at the time of writing.

1.6 Notable implant “milestones”

NIH Harvard Conference, 1978

The U.S. National Institutes of Health (NIH) sponsored a consensus conference to review the status of oral implantology (Schnitman and Shulman 1980). The foremost experts in the field from around the United States presented

the state of the art and science of oral implantology at this meeting. A consensus report was published giving clinical guidelines for the use of the various implant modalities including subperiosteal, blade, staple, and vitreous carbon. Root-form Ti endosseous implants were not on the meeting schedule, as European implant research was not represented.

Toronto Conference on Osseointegration, 1982

George A. Zarb, at the University of Toronto, recognized the potential of Brånemark’s work with Ti screw implants and was instrumental in organizing the first North American Conference on Osseointegration in May 1982 (Zarb 1983). Brånemark presented the results of his group’s research to a North American dental audience for the first time. He and his colleagues presented the biology of the implant-tissue interface and the results of 15 years of controlled clinical implant trials on edentulous subjects (Adell et al. 1981). This conference produced a paradigm shift in implant dentistry and the treatment of edentulism. Zarb and his colleagues was the first research group outside of Sweden to replicate and verify the clinical results obtained by the Brånemark group (Zarb and Schmitt 1990).

NIH Conference, 1988

The U.S. National Institute of Dental Research (NIDR), the U.S. NIH, and U.S. Food and Drug Administration (FDA), convened the conference to assess the rapid growth and advances in implantology in the early 1980s in the United States, Europe, and Japan (NIH 1988). The conference aimed to deal with gaps in knowledge and tried to resolve some existing controversies. The conference report emphasized the need for a multidisciplinary approach due to the complexity of the surgical and restorative

procedures. The report noted the need for more controlled animal studies and clinical research, that is, randomized controlled trials (RCTs). The report also noted that it was not possible to make a definitive statement on long-term efficacy of dental implants. It was recognized that a large proportion of endosseous, subperiosteal, and transosteal implants had remained in place for more than 10 years.

1.7 Criteria for implant success

Ultimately, a long-term, functional, and stable aesthetic restoration on a stable integrated implant is the desirable outcome for both patient and dentist. Clinical implant cases may be considered a failure when the implant is failing or has failed, or when the prosthesis has aesthetic or persistent mechanical problems. The main predictors for implant survival are the quantity and quality of bone, age of patient, certain systemic health factors, smoking, the dentist's experience, loading conditions, implant length, and oral hygiene (Porter and von Fraunhofer 2005).

Implant success and survival

Albrektsson et al. (1986) designated success criteria as follows:

- The individual implant should be *clinically immobile*.
- There should be *no radiographic radiolucency*.
- There should be an *absence of persistent pain, infections, neuropathies, and paresthesia*.
- There should be *85% implant survival at the end of a 5-year period* of observation and *80% at the end of a 10-year* observation period.
- There should be *less than 0.2 mm of bone loss annually* following the implant's first year of loading.

Roos et al. (1997) proposed an update to these criteria to reflect that, as implant design evolved, early bone loss could be further minimized. The new criteria suggested a figure of <1.8 mm bone loss for the first 5 years.

- Less than 1.0 mm bone loss in the first year
- Less than 0.2 mm bone loss annually after the first year
- Functional survival of 90% after 5 years and 85% after 10 years.

Implant and prosthetic success

Implant success is predicated on the usefulness of the implant. Implant position should allow the fabrication of a successful prosthesis. Similarly, the prosthesis must be conducive to implant hygiene and transmit physiologic forces to the peri-implant bone. Criteria for success in implant dentistry have been reviewed by Papaspyridakos et al. (2012) and include:

- *Patient satisfaction*: comfort, function, aesthetics, and general satisfaction
- *Peri-implant bone health*: absence of bone loss, mobility, infection, and pain
- *Peri-implant soft tissue health*: healthy probing depth; absence of suppuration, bleeding on probing, edema, hyperplasia, swelling, and recession
- *Prosthetic success*: good function and aesthetics, with no or minor complications.

Outcome criteria vary from study to study, which makes it difficult to compare studies even about the same implants. Of the success criteria used, the most frequent is *implant survival* over the fixed time span of a study. Using this criterion, an implant may be considered a statistical survival success even if there is progressive bone loss or the implant prosthesis fails. Many studies cover a very limited time-span in terms of number of years or even months.

Another factor to be borne in mind when evaluating research or attending continuing education courses, is whether there is a research bias, or whether researchers have a conflict of interest, that is, whether their research is supported by an implant company. (Popelut et al. 2010).

1.8 Clinical studies, implant validation

Numerous clinical studies have documented the successful use of implants for tooth replacement in fully and partially edentulous patients. Expert clinical teams, in controlled conditions and with careful case selection, have conducted the vast majority of studies. PubMed, the Cochrane Library, and the ADA Evidence Based Dentistry website are good sources for systematic reviews of implant research topics.

Today, a single tooth implant replacement has the expectation of a 95% success rate (Sullivan 2001; ADA 2004; Jokstad 2009). In one of the earliest longitudinal clinical trials, Adell et al. (1981) reported implant survival of 81% (maxilla) to 91% (mandible), and a fixed full-arch prosthesis survival rate of 89–100%; peri-implant bone loss was 1.5 mm after 1 year and did not exceed 0.1 mm/year thereafter. Buser et al. (1997) wrote that the success of dental implants is well documented and an implant survival rate greater than 90% should be achievable. Esposito et al. (2003) found no differences in bone levels and failure rates for six different implant systems.

Many other studies have validated the success of implants (Albrektsson et al. 1988; Jemt et al. 1989; Adell et al. 1990; Zarb and Schmitt 1993; Lekholm et al. 1999). Authors (Berglundh et al. 2002; Lang et al. 2004) have reported 5-year survival rates of 97.5% for single crowns, 95.4% for FDPs, 94% for overdentures and a 10-year survival rate of 92.8% for FDPs. Berglundh et al. (2002), examining 10 implant systems, reported the loss of 2.5%

implants before functional loading. Implant loss during function ranged from 2% to 3% for fixed prostheses, and 5% for overdentures over a 5-year period. Implant loss for augmented ridges was significantly higher, 11.3% after 5 years. Single-implant crowns had the lowest rate of implant loss in function, 2.2%.

1.9 Implant regulation

Since 1985, the ADA had a program for Approval and, later, Acceptance for Dental Implants (ADA 2004). This Seal program was terminated in 2007. The United States and European Union have medical device regulatory guidelines (EU Standards 1993; U.S. FDA Regulations 2004).

In 1998, the FDA reclassified Ti dental implants from Class III to Class II medical devices. Class II devices need laboratory and animal testing, but not clinical human testing. Since the reclassification by the FDA of implants, there has been a proliferation of new implant systems. The vast majority of implant brands on the market today have zero clinical documentation (Jokstad 2009).

In 2003, the World Dental Federation (also known as the FDI as it was begun in France as the Fédération Dentaire Internationale) studied the issue of proliferating implant systems (Jokstadt et al. 2003) and identified 225 implant brands from 78 manufacturers. Of these, only 10 systems had more than four clinical trials, and 11 had less than four clinical trials of good methodological quality. 28 manufacturers sold implant systems without any published clinical documentation. The FDI suggested that the dental profession use implant systems that are supported by sound clinical research documentation and which conform to good manufacturing practice in compliance with International Organization for Standardization (ISO) standards, or FDA, or other regulatory standards. More than 50% of all trials reported have been on implants manufactured

Table 1.1 Clinical trials published since 2003 ($n = 530$) sorted according to implant brand

Implant brand	No. of studies	%
Nobel Biocare: Branemark/Replace/Nobeldirect/Nobelperfect/SteriOss, etc.	176	33
Straumann/ITI	101	19
Dentsply: Frialit/Frialit2/Frialit+/Friadent/Frialoc/Frios/Xive/Ankylos	53	10
Biomet 3i: Osseotite/Nanotite	41	8
Astra	23	4
Zimmer: Calcitek/Integral/Omniloc/ScrewVent/Spline/SwissPlus, etc.	22	4
IMZ	16	3
Camlog	7	1
Biohorizons/Maestro	6	1
Southern Implants	5	1
Bicon	5	1
Defcon	4	1
Sweden & Martina	4	1
Other or not stated	67	13

Source: Adapted from Jokstad (2009).

by Nobel Biocare and Straumann, and 80% of all clinical trials were limited to clinical reports conducted on implants from the first six manufacturers in Table 1.1. Bhatavadekar (2010) reviewed the literature for randomized controlled clinical implant trials and corroborated Jokstad's findings.

The onus is on the clinician to make an informed choice of the most suitable implant system for the patient's long-term benefit. This should be based on the clinical evidence, the track record, and service offered by the implant company.

1.10 Research and development

Dental implant treatments have come a long way in a short period of time. The ingenuity of implant companies and dental professionals to reinvent and tweak the designs and applications is remarkable. We still do not have scientific rationale for implant length, size, and number relative to load, nor the precise mechanics of functional loading. Destructive peak loads may be a problem, as we tend to think in

terms of average occlusal forces on natural teeth that can move in function. We need a better understanding of bone response to *functional forces* and *overload*. There is still much work to be done in terms of answering fundamental questions of biology, and day-to-day treatment planning of implant supported tooth replacement. Surgical techniques continue to evolve with guided surgery, and bone augmentation solutions. Currently, there are some key areas of interest in implantology:

- Surface modification: optimizing implant design to enhance the rate of osseointegration and percentage of implant bone contact.
- Peri-implant infection (bone loss) and its management. There is controversy as to whether bone loss can be attributed to adverse biomechanical loading or whether it is simply analogous to periodontal breakdown around natural teeth.
- Ridge augmentation and guided bone regeneration
- Computer guided implant placement
- Early loading protocols and bone healing

1.11 Summary

Some of the original prostheses placed in the 1960s on Brånemark implants are still functioning today (Brånemark 2006). It is a testament to the remarkable work of Brånemark and other researchers that the original placement protocol remains essentially unchanged, and that the original implant design is still a reference and widely copied. As word spread in the dental community about osseointegration, there was a certain amount of skepticism because of the radical nature of this development. As acceptance grew so also did the input of the working dentists, bringing innovation and modification of the early Brånemark protocol and implant design. At present, certain restorative treatments have become accepted as routine procedures for general dentists namely single crowns, small multi-unit fixed prostheses, and mandibular overdentures supported by two implants.

The ADA dental education accreditation guidelines (ADA 2013) mandate competency in implant treatment. European dental education and Australian dental education have embraced implantology by producing undergraduate educational guidelines (Hicklin et al. 2009; Mattheos et al. 2009; Mattheos et al. 2010).

Evolution of surgical techniques and component design has resolved many of the early problems with implants, and today we have many excellent implant systems of high quality and utility. The technology has expanded in line with the demand for usage by the public and dentists, and finances may now be the only limitation to their universal use.

Finally, this author would highly recommend Froum's (2010) textbook on complications as a reference when embarking on implant practice.

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