



Review Article

A brief history of osseointegration: A review

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ABSTRACT

Background: osseointegration of dental implants refers to direct structural and functional link between living bone and the surface of non-natural implants. It follows bonding up of an implant into jaw bone when bone cells fasten themselves directly onto the titanium surface. It is the most investigated area in implantology in recent times. Evidence based data reveals that osseointegrated implants are predictable and highly successful. This process is relatively complex and is influenced by various factors in formation of bone neighbouring implant surface.

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1. Introduction

Missing teeth and their various attempts to replace them has presented a treatment challenge throughout human history. Different procedures initiated have resulted with varied success. However with studies conducted by Branemark and colleagues using titanium chamber gave rise to the concept of osseointegration. Osseointegration was initially defined on the light microscopic level as a direct structural and functional connection between ordered living bone and surface of load carrying implants.¹

Osseointegration was first defined as a direct contact between living bone and the surface of a load-carrying implant at the histological level.²

It is a process where by clinically asymptomatic rigid fixation of alloplastic material is achieved and maintained in bone during functional loading” – “Functional ankylosis”.³

“It is the direct anchorage of an implant by the formation of bone directly on the surface of an implant without any intervening layer of fibrous tissue.”⁴

1.1. History

An investigational work was carried out in Sweden by Professor Per-Ingvar Branemark and his colleagues from 1950 to 1960. It was in 1952 Dr. Per-Ingvar Branemark discovered that titanium glued well with bone; a spectacle which was later termed as osseointegration.⁵ In 1965, Dr. Branemark and his associates started clinical trials with titanium dental implants with great success. Dr. Per-Ingvar Branemark, had studied the theory of tissue united prosthesis at the Laboratory of Vital Microscopy at the University of Lund, and consequently at the Laboratory for Experimental Biology at the University of Gothenburg.² In the early 1960s, Branemark and co-workers at the University of Goteborg started developing a unique implant that for clinical function depended on direct bone anchorage termed osseointegration. He discovered a strong and direct bone anchorage of a titanium chamber while reviewing microcirculation in bone repair mechanisms.

In 1970s- there were no methods available to section intact bone to metal specimens.² Therefore, the histologic evidence of osseointegration remained indirect. Only after removal of the implant with potential simultaneous

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removal of some soft interfacial tissues was it possible to inspect and analyze the interface. The first investigator to clearly demonstrate osseointegration was Schroeder from Switzerland.^{6,7}

Schroeder⁷ worked from the mid 1970s, quite independently from Branemark, with research on direct bone anchored implants. Schroeder's team used newly developed techniques to cut through undecalcified bone and implant without previous separation of the anchorage. In, for their time, excellent illustrations, a direct bone to implant contact was proved beyond doubt (Schroeder et al. 1976, 1978, 1981).

In 1973-Cameron et al. had shown that bone may grow on the surface of a biocompatible material. This only happens if movement between the implant and adjacent bone is prevented until osteogenesis is complete.

In 1973- Cameron et al.⁸ noted that no bonding occurred when porous vitallium staples were inserted across an unstable osteotomy site. Bone in growth therefore does not occur with movement above a certain magnitude and mechanical fixation then becomes necessary.

In 1978- Other pioneering work on osseointegration was conducted at roughly the same time by the German clinical scientist Schulte.⁶

In 1979-Brunski et al.⁹ using pure-breed beagle dogs as an experimental model, compared the tissue-implant interfaces of functional and non-functional endosseous implants histologically for up to one year after surgery. They noted that fibrous capsulation (non-mineralized connective tissue zone) occurred with the functional implants, on which there were apical loads, but direct bone apposition occurred with the non-functional implants, on which there were no apical loads.

In 1988- Lindquist et al.⁹ stated that the long-term prognosis for osseointegrated fixtures was extremely good. The bone loss was less than 0.1 mm per year after the post-surgical period.

The history of the Branemark System can be categorized into three stages:¹⁰

The early stage (1965-1968),

The developmental stage (1968-1971) and,

The production stage (1971-present) (Adell, et al., 1981).

The system in use includes surgical components and drilling equipment that were established in early 1971. In January 1986, the Branemark Clinic for osseointegration implant treatment was established within the School of Dentistry at Goteborg University.

1.2. Bone

Osseointegration is a constant procedure representing process of formation and adaptation to function and repair, which is due to Osteoblastic and Osteoclastic activity of bone, also known as coupling.¹¹⁻¹³

Histology of bone: Osseous tissue is a rigid form of connective tissue and is normally organized into definite structures, the bones.¹⁴ Bone consists of cells and intercellular matrix of organic and inorganic substances.

The cells present are called osteocytes; they are located in lacunae and have cell processes for nutrient diffusion within small channels or canaliculi.

The organic matrix component or osteoid is approximately 40% by weight, and consists of Type I collagen, glycosaminoglycans, and the adhesive protein, osteonectin. It is referred to as osteoid before mineralization, which is primarily collagen fibers embedded in ground substance. This ground substance is a viscous gel of water and glycoprotein or protein complexes. It also consists of numerous organic factors (cytokines, growth factors) that help control cell activation, matrix maturation and mineralization. Collagenous fibers forms the major protein of the organic component of the bone.

The inorganic component is also approximately 40% by weight and consists of hydroxyapatite, the apatite crystal of calcium and phosphate. Responsible for rigidity of bone and constitute about 2/3 of the bone weight.

Calcium phosphate 85%

Calcium carbonate 10%

Calcium fluoride

Magnesium fluoride

X-ray diffraction studies shows that minerals are present in the form of crystals having an apatite pattern more specifically they are hydroxyapatites.

1.3. Histological classification of bone:¹⁵

Compact bone (referred to as cortical bone) or

Spongy bone (referred to as cancellous bone).

The spongy and compact bone have the same types of cells and intercellular substances but they differ from each other in arrangements of their components and in the ratio of marrow space to bone substance. In spongy bone the marrow space are relatively large and irregularly arranged and the bone substance is shaped as slender spikes and trabeculae.

In compact bone, the space or channels are narrow and the bony substance is densely packed. The most characteristic features of adult tissue are its lamellar structure, the fibers and calcified matrix being organized into thin layers of lamellae arranged in various ways.(Figure 1)

1.3.1. Woven Bone (Non Lamellar)

Woven bone is formed rapidly approximately 30 to 50 μm / day in the vicinity of blood vessels during prenatal development growth and bone healing phase. This bone is thus richer in cells and shows an apparently irregular arrangement of collagen fibers. Moreover they have low mineral content and decrease mechanical strength.



Fig. 1: Structure of bone: Cortical bone, Haversian system and harder structure compared to spongy bone with a porous structure.

1.4. Bone density classification schemes related to implant dentistry

Linkow in (1970) classified bone density into 3 categories.¹⁶

Class I Bone structure: Ideal bone type, consists of evenly spaced trabeculae with small canceled space. This bone provides very satisfactory foundation for implants.

Class II Bone structure: Slightly larger canceled space with less uniformity of osseous pattern. This bone provides satisfactory foundation for implants.

Class III Bone structure: Large marrow filled space exists between bone trabeculae. This bone density is not adequate, and hence implant are loose fitting.

1.5. In 1985 Lekholm and Zarb listed 4 bone qualities

Quality Q1: Homogenous compact bone.

Quality Q2: Thick layer of compact bone surrounding a cone dense trabecular bone.

Quality Q3: Thin layer of cortical bone surrounding dense trabecular bone.

Quality Q4: Thin layer of cortical bone surrounding low density trabecular bone.

1.6. Misch bone density classification¹⁴

In 1988 Misch extended four bone density groups independent of regions of jaw based on macroscopic cortical and trabecular bone. Dense and/or porous cortical bone is found on the outer surface of the bone and includes the crest of the edentulous ridge. Course and fine trabecular bone are found within the outer shell of cortical bone.

D1: Dense cortical bone

D2: Thick dense to porous cortical bone on the crest and coarse trabecular bone within.

D3: Thin porous cortical bone on the crest fine trabecular bone within.

D4: Fine trabecular bone.

D5: Immature, non-mineralized bone.

Studies of the Branemark System over the last 20 years have shown a 10% higher implant failure rate in soft maxillary bone in comparison to the dense bone of the mandible.⁷ In one five-year study, an implant failure rate of 35% was documented for Branemark implants placed Type IV bone. This failure rate was 32% higher than the cumulative failure rate for all implants placed in Types I-III bone reported in the same study.

To preserve a persistent level of bone remodelling, there should be appropriate local stimulation as well as crucial levels of thyroid hormone, calcitonin, and vitamin D within the system. Occlusion or occlusal force stimulus, and general health management are both important for perfect bone remodelling at the fixture locations.¹⁷

There are two basic theories regarding the bone-implant interface and retention of an endosteal implants in function. They are:

1. Fibro-osseous integration supported by Linkow (1970), James (1975), and Weiss (1986).⁹
2. Osseointegration supported by Branemark (1985).¹⁴

1.7. Stages of Osseointegration

In bone defects, principal fractures and in Osseointegration the healing is stimulated by any lesion of the pre-existing bone matrix. When the matrix is open to extracellular fluid, noncollagenous proteins and growth factors are released and activate bone repair takes place.

Osseointegration follows a common, biologically determined program that is subdivided in to 3 stages:

1. Incorporation by woven bone formation.
2. Adaptation of bone mass to load (lamellar and parallel-fibered bone deposition).
3. Adaptation of bone structure to load (bone remodelling).

1.8. Key factors responsible for successful Osseointegration

There are several reasons for primary as well as secondary failure of osseointegration. These failures may be attributed to an inadequate control of the six different factors known to be important for the establishment of a reliable, long-term osseous anchorage of an implanted device. These factors are:¹⁸

1.9. Implant Material Biocompatibility

1. Implant design characteristics
2. Implant surface characteristics

3. Bone density quality
4. Surgical considerations
5. Loading conditions

1.10. Implant design characteristic

Implant design refers to the 3D organization of the implant i.e., form, configuration, geometry, contour, surface macro irregularities and macro structure. Exactitude fit in the vital bone leads to osseointegration. At present, satisfactory long-term documentation solitary on threaded types of oral implants that have been established to function for decades devoid of clinical problems. Various implant designs are cylindrical, screw shaped implants, Threaded and Non threaded Cylindrical implants / press fit implants: They lead to stark bone resorption due to micro movement of the implant in the bone. Alberktsson in 1993 reported that enduring bone saucerization of 1mm – first year, 0.5 mm annually and there after cumulative rate of resorption up to 5 year follow up.

1.10.1. Threaded Implants

1. Documentation for long term clinical function
2. Modification in the design, size and pitch of the threads can affect the long term osseointegration.

1.10.2. Advantages of Threaded Implants

1. Load distribution for stress is better as the functional area is more than the cylindrical implants.
2. Threads enhance the primary implant stability and evade micro movement of the implants till osseointegration is reached.
3. The various forms of threads are: Standard V – thread, Square thread, Buttress thread.
4. The threaded portion of a screw-shaped implant has three typical regions: the top, the flank and the valley region. Of the three different sites, the top region frequently has the roughest surface.²⁰ If we assume that all parts of an implant are equally important with respect to osseointegration, a proper characterization of the implant surface must include measurements made in all 3 areas. Alignment of irregularities may give isotropic surface & anisotropic surface.
5. Wennerberg 2000 reported that improved bone fixation (osseointegration) will be attained with implants with an enlarged isotropic surface as matched to implant with turned anisotropic surface structure.²¹

1.10.3. Different machining process results in different surface topographies

1. Turned surface / machined surface.
2. Hydroxyapatite coated surface
3. Acid etch surface – Hydrogen Chloride (HCl) & Sulfuric acid (H₂SO₄).

4. Blasted surface – Titanium dioxide (TiO₂) /Aluminium oxide (Al₂O₃) particles.
5. Blasted + Acid etch surface(SLA surface); AL₂O₃ Particles, HCl, H₂SO₄ Tri calcium phosphate, Hydrogen fluoride & Nitrate
6. Titanium plasma sprayed surface
7. Nano sized hydroxyapatite coated surfaces.

With respect to the deceptive topography there is strong documentation that most plane surfaces don't result in antolerable bone cell adhesion. Such implants do consequently get anchored in soft tissue even with the best material used.

Carlsson et al published evidence of dominance of the threaded design in osseointegration compared with plates and several irregular implant shapes.²²

Kasemo and Lausmaahave summarizedstandpoints on the implant surface and made 3 important conclusions:²³

1. It is not possible to predict how surface change status affects the long-term function of an implant.
2. The surface status of a particular implant material may vary widely depending on its preparation and handling.
3. The surface status of implants is crucial for in vivo function and should therefore be specific and standardized.

1.11. Osteopromotion

It is the procedure to enhance the formation of bone approximating the implant surface using bone regeneration techniques (using Polytetrafluoroethylene membrane).Bone growth factors like Platelet-derived growth factor (PDGF),Insulin-like growth factor (IGF), Plateletrich plasma,transforming growth factor (TGF – B1)stimulates osteoprogenitor cells, enhance the bone growth. Stefini CM et al (2000) recommend applying PDGF and IGF on the implant surfaces afore placing in to cervical bed. This technique showed improved wound healing and prompt osseointegration.²⁴

1.12. Indications

1. Localized ridge augmentation preceding to placement.
2. Situations with deficient alveolar bone volume.
3. Treatment of peri implant bone defect.

1.13. Selection and Preparation

The surgeon with judgement should carefully evaluate the patient prior to recommending implants. Evaluation should include^{25,26}

1. Consultation.
2. Oral examination
3. Radiographic assessment.

Table 1: Implant material biocompatibility:¹⁹

Biological Biocompatibility	Chemical Composition		
	Metals	Ceramics	Polymers
Biotolerant	Gold Cobalt-Chromium Alloys Stainless Steel Zirconium Niobium Tantalum		Polyethylene Polyamide Poly-methyl methacrylate Poly-tetrafluoro ethylene Poly-urethane
Bioinert	Commercially Pure Titanium (Cpti) Titanium Alloy (Ti-6-Al-4v)	Aluminium Oxide Zirconium Oxide	
Bioactive		Hydroxyapatite, Tricalciumphosphate Tricalciumpyrophosphate Fluorapatite Carbon: Vitreous, Bioglass	

4. Diagnostic casts mounted on an appropriate articulator.

Several matters merit attention during the evaluation stage:

1. Age
2. Medical status
3. Patient motivation
4. Concurrent drug therapy
5. Informed consent

1.14. All patients are recalled at least annually for examinations, which include the following:

1. Patient's opinion of the treatment result
2. Bone characteristics
3. State of bridge occlusion and stability
4. State of oral hygiene
5. Mechanical component conditions.

1.15. Success criteria for osseointegrated implants

Smith D.E et al.²⁷ examined the possible criteria for implant success in the light of available supporting studies for implant success.

1.16. Consideration should be given to evaluating the following criteria:²⁸

1. Durability
2. Bone loss
3. Gingival health
4. Pocket depth
5. Effect of adjacent teeth
6. Function
7. Esthetics
8. Presence of infection, discomfort, paresthesia or anesthesia
9. Intrusion on the mandibular canal
10. Patient emotional and psychological attitude

1.17. Mobility

Picon et al used a strain gauge transducer to measure the mobility of titanium blade implants 9 months after placement. With a loading force of 6N horizontal and vertical displacement were at a lower order.

Fenon et al measured the mobility of osseointegrated threaded titanium fixtures after 3 years in function. They used a linear variable displacement transformer to measure buccal displacement under a lingual applied force of 500 gm. The displacement recorded was 10 μ m compared with 47 μ m for natural teeth

An additional test is to rap the implant with an instrument. If the tap elicits a solid ring there is no mobility but if the sound is dull the implant is presumed not be osseointegrated and therefore surrounded by fibrous tissue.

Implants that have been shown to the formation of fibrous tissue interface with the implant demonstrate a 5-10 year, Clinical success rate.

1.18. Peri-implant radiolucency

In some ways mobility and peri-implant radiolucency measure the same aspect of implant response. A complete peri-implant radiolucency indicates the presence of soft tissue and probable implant mobility and is a predictor of impending implant loss. The periapical radiograph gives a two dimensional image that is only useful to evaluate the mesial and distal surface of implant. No information is provided to the status of buccal and lingual aspects. Thus a considerable portion of the surface **is not** accessible for evaluation.

1.19. Marginal bone loss

Stability of bone support for the implant is an important criteria for determining success. Without relative stability of the level of the bone, the implant is doomed to failed.

Smithoff and Fritz observed sulcus depth of 5 to 8 mm into the buccal and lingual aspect of blade implants after

10 years. Adel et al demonstrated that mean bone loss for Branemark osseointegrated implant is 1.5 mm for first year followed by mean bone loss of 0.1 mm per year.

1.20. Sulcus depth

Many clinical evaluations of implants have used sulcus depth as a measure to evaluate implant success. However there is little information that depth is related to implant success.

1.21. Gingival status

Branemark et al in their experiments noted that the implants used had been successful even in the absence of oral hygiene procedures. Adel et al in a 3 year longitudinal prospective study on 16 consecutively treated patients with 95 osseointegrated fixture found that 80 to 85% of implants are without clinical inflammation.

1.22. Damage to adjacent teeth

Although an implant that is impinging on the adjacent root could not be considered successful even though the implant and the tooth survived, this problem is one iatrogenic origin.

1.23. Persistent infection

Implants that are the source of persistent or recurrent infection should not be considered successful.

1.24. Revised criteria for implant success:²⁹

1. Individual unattached implant is immobile when tested clinically
2. No evidence of peri implant radiolucency is present as assessed on an undistorted radiograph
3. Mean vertical bone loss is less than 0.2 mm after 1st year of service
4. No persistent pain, discomfort or infection
5. A success rate of 85% at the end of a 5-year observation period and 80% at the end of a 10-year period are minimum levels of success.

Saadoun A.P et al,³⁰ discussed the keys to success in implant osseointegration. Quality of bone is the determining factor in success rates; the deeper the bone, the lower the failure rate; a failure rate is most likely to take place during the first year after placement; a higher success rate is found in the mandible; and a higher success rate is found with HA-coated implants.

1.25. Methods of evaluation of osseointegration:

1.25.1. Invasive methods

1. Histological sections
2. Histomorphometric

3. Transmission electron microscopy
4. Pull out tests
5. By using torque gauges

Historically, microscopic or histologic analysis has been considered as the gold standard method to evaluate the degree of osseointegration. However, due to the invasiveness of this method and related ethical issues, various other methods of analysis have been proposed.

1.25.2. Non-invasive methods

1. Percussion test: An osseointegrated implant makes a ringing sound on percussion whereas an implant that has undergone fibrous integration produces a dull sound.
2. Radiographs
3. Reverse torque test: A reverse or unscrewing torque is applied to assess implant stability at the time of abutment connection. Implants that rotate under the applied torque are considered failures and are then removed.
4. Periotest: It is a device which is an electrically driven and electronically monitored tapping head that percusses the implant a total of 16 times in about 4s.
5. Resonance frequency analysis: It measures implant stability and bone density at various time points using vibration and structural principle analysis. Classically, the implant stability quotient (ISQ) has been found to vary between 40 and 80, the higher the ISQ, the higher the implant stability. It is inversely proportional to the resonance frequency. Implant stability can be determined for implants with an ISQ of 47. All implants with an ISQ more than 49 osseointegrated when left to heal for 3 months. All implants with an ISQ more than 54 osseointegrated when immediately loaded.

1.25.3. Evaluation of success of osseointegration:

Alberktsson Success Criteria (1986)³¹

1. The individual unattached implant should be immobile when tested clinically
2. The radiographic evaluation should not show any evidence of radiolucency
3. The vertical bone loss around the fixtures should be less than 0.2 mm per year after first year of implant loading.
4. The implant should not show any signs of pain, infection, neuropathies, parasthesia, violation of mandible canals and sinus drainage.
5. The success rate of 85% at the end of 5 year and 80% at the end of 10 years.

According to the present concepts the width of the attached gingival, co‑existing medical conditions, smoking,

width of the implant, suture material used, all play an important role in implant success. Even genetic and immunological factors like TNF- α and IL-1 β have been identified as markers for implant success.³²

2. Conclusion

Osseointegration is one of the most critical aspects in implant success. Successful osseointegration is a mandatory for functional dental implants. It is necessary to be aware of the mechanism of osseointegration in order to direct research to enhance success. Various researchers have focused on the hardware aspect of an implant to yield better results, however the recent developments in surgical techniques such as Osseo densification have opened new arrays for research into the field of implants.

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4. Conflict of Interest

The authors declare they have no conflict of interest.

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