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Review article

Optimal implant stabilization in low density bone

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Abstract: Initial stability of the implant is one of the fundamental criteria for obtaining osseointegration. An adequate primary anchorage is often difficult to achieve in low density bone (type IV). Various surgical suggestions were advanced in the 1980s which were aimed at achieving optimal osseous integration in poor quality bone. They offered satisfactory short-term results. Recently, as a result of surgical and technological innovations, new therapeutic proposals have shown very interesting results in their initial studies.

The highly satisfactory success rate obtained with dental implants in the treatment of various edentulous cases depends upon the volume and quality of the bone (Adell et al. 1981; Albrektsson et al. 1988; Engquist et al. 1998; Zarb & Schmitt 1990; Henry et al. 1993). Initial stability of the implant is, in effect, one of the fundamental criteria for obtaining osseointegration (Albrektsson et al. 1981). Achieving stability depends on the bone density, on surgical technique, and on the microscopic and macroscopic morphology of the implant used. In bone which is not very dense, it is often difficult to obtain implant anchorage. The lack of initial stability in type IV bone results in lower success rates (Fig. 1), which vary from 50% to 94%. This type of bone is often present in the posterior areas of the jaws (Lekholm & Zarb 1985; Jemt 1991; Truhlar et al. 1997).

Numerous animal studies confirm the importance of adequate implant anchorage to obtain osseointegration. Sennerby et al. (1992) showed, in the rabbit, that implants stabilized by only 3 threads in cortical bone, had a higher percentage of bone to implant contact and an increase of the forces necessary to dislodge the implant compared to implants which had been completely surrounded by trabecular bone. According to these results, the amount of bone in the cortical passage is important for optimal implant stabilization. Sennerby et al. (1992) suggested that implant placement through two cortices is probably preferable in regions with low bone density. Recently, Ivanoff et al. (1996), again in the rabbit, analyzed the amount of bone implant contact as a function of initial stability. According to these authors, initial rotational mobility, whether it is in dense or spongy bone, does not cause a great difference in the amount of bone to implant contact. Very few human clinical studies have reported results on the quality of bone healing around movable implants during insertion. Friberg et al. (1991) reported an implant failure rate of 32% for those implants which showed inadequate initial stability.

Optimal implant stabilization can be

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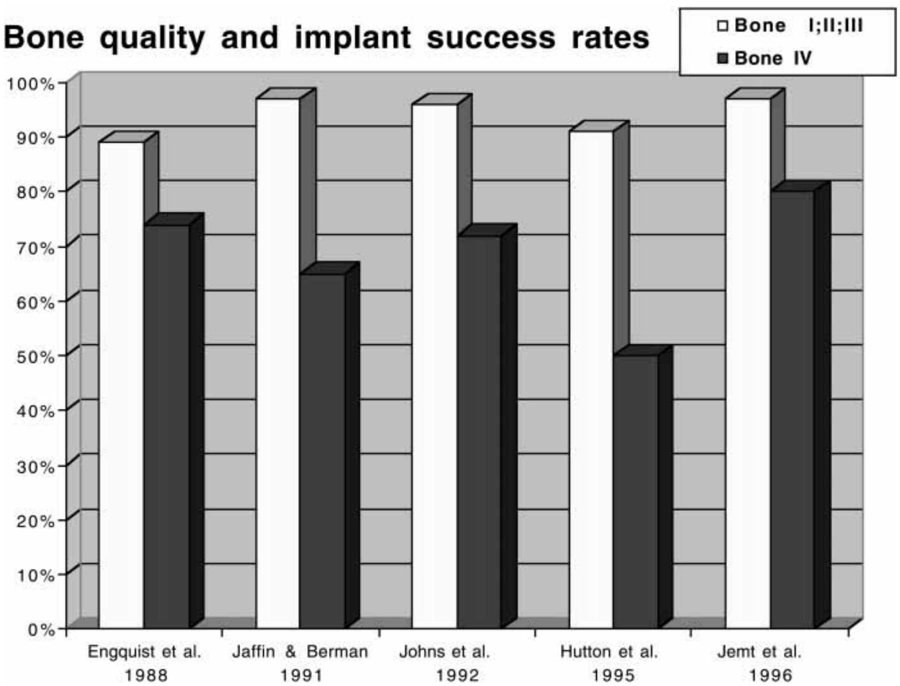

Fig. 1. Implant success rates as related to bone quality.

defined as the lack of mobility at stage I surgery. The aim of this review article is to set forth the various implant and surgical options which enable the practitioner to achieve optimal initial implant stability in sites where bone density is not very favorable.

Bone diagnosis

Evaluation of bone density

Radiographic examination only allows us to crudely evaluate the bone quality of the edentulous site. Computer tomography (CT) offers the best radiographic method for the morphological and qualitative analysis of the residual bone (Andersson & Svatz 1988; Quirynen et al. 1990; Lacan 1999) (Fig. 2). CT software programs (Dental PC – General Electrics) facilitate the evaluation of the bone density by Hounsfield Units (HU): very dense cortical bone (>600 HU); dense cortical-spongy bone (between 400 and 600 HU); cortical-spongy bone of low density (<200 HU) (Fig. 3) (Lacan & Teman 1999). CT Hounsfield Units are only of use in determining bone density if a standard reference is used upon imaging. Clinically, bone density is evaluated by tactile perception during the preparation of the implant site (Engquist et al. 1988; Jaffin & Berman 1991). This subjective approach permits the adaptation of the surgical sequence before the insertion of the implant. New methods using electronic systems have been used in animal studies in order to determine the bone quality as related to the frictional forces generated during surgical preparation and implant placement (Johansson & Strid 1994; Friberg et al. 1995). In 1997, Nobel Biocare proposed a new motor equipped with a graphic presentation screen which enabled the evaluation of bone quality during bone drilling and implant placement (Love 1997). The best biologic method for evaluating the bone density is histomorphometric analysis of a bone sample (Friberg et al. 1995). However, this approach is not applicable to clinical prac-

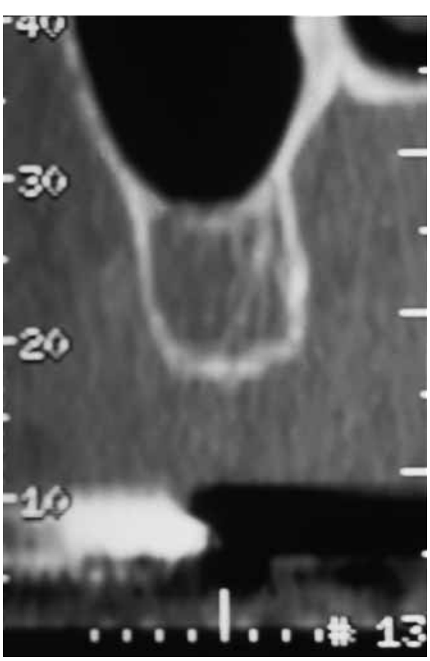

Fig. 2. Oblique CT scan cut showing a low density bone (type IV).

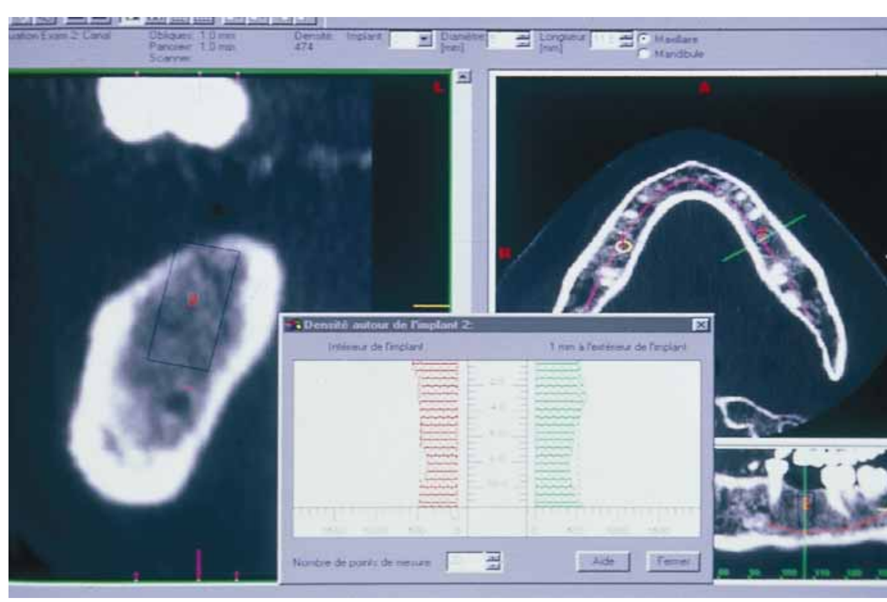

Fig. 3. Bone density could be evaluated on new CT scan software.

Bone	Characteristics and quality of the bony layers
Type I	Almost the entire jaw is comprised of homogenous compact bone.
Type II	A thick layer of compact bone surrounds a core of dense trabecular bone.
Type III	A thin layer of cortical bone surrounds a core of dense trabecular bone of favorable strength.
Type IV	A thin layer of cortical bone surrounds a core of low density trabecular bone.

Fig. 4. Bone quality according to Lekholm & Zarb (1985).

tice. Trisi & Rao (1999) presented a study of the correlation of clinical and histomorphometric findings of bone densities obtained after the placement of implants in 56 patients. According to these authors, tactile perception permits the differentiation, to a statistically significant degree, between highly cortical bone type I and low density bone type IV (Fig. 4). On the other hand, the differentiation between intermediate quality bone (types II and III) is not viable with tactile perception (Trisi & Rao 1999). Therefore, in clinical practice, tactile perception allows us to classify the bone quality into three categories: soft, normal and dense bone.

Evaluation of primary stability

Classically, the notion of primary stability has been a very subjective one. It is based on the tactile perception of the surgeon. Three types of mobilities may be defined using this clinical evaluation system: a non-mobile implant; a partially mobile implant which is horizontally stable but rotates; and a mobile implant, which demonstrates lateral or vertical movement (Orenstein et al. 1998). A mobile implant must be removed and replaced by a longer and/or larger implant (Langer et al. 1993).

The analysis of the resonance frequency is a new, non-invasive clinical method of determining the primary and secondary stability of the implant (Meredith et al. 1996). A system of transductors fixed either directly on the implant or on the abutment permits the analysis of the resonance frequency using specially designed software (Sennerby & Meredith 1999). The resonance frequency depends on the rigidity of the bone-implant interface and on the distance between the transductor and the first point of the bone–implant interface (Meredith 1997). This technique is better for confirming primary and secondary stability in the mandible than in the maxilla (Meredith et al. 1997). Very recent studies using this new tool allow us to respond to certain dogmas prevalent in modern implantology. The initial stability of an implant varies according to the quality of bone. Curiously, Friberg et al. (1999) have shown very satisfactory bone healing in low density bone. Indeed, the increase in anchorage of an implant placed in low density bone is greater than that of an implant placed in dense bone, after 8 months of bone healing. It seems that implants placed in bones of different densities orient themselves towards a similar degree of secondary density after one year of loading (Sennerby & Meredith 1999). This observation confirms the idea that a longer healing period is necessary for implants placed in low density bone (Johansson & Albrektsson 1991). On the contrary, it is interesting to note that the stability of anterior mandibular implants showed minor differences from the day of placement to the connection of fixed prostheses (Friberg et al. 1999). According to these authors, it may be concluded that anteriorly placed mandibular implants are as stable in the immediate postoperative period as they will be after the recommended healing (3 to 4 months).

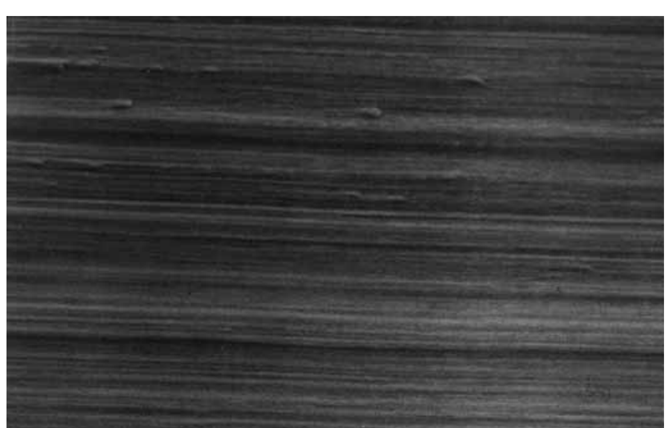

Fig. 5. Scanning electron microscope photomicrograph of a machined implant surface (magnification ×2000).

Early therapeutic proposals

Rough surfaces

Titanium implants with smooth machined surfaces have been used for a longer time than all other types of implants (Fig. 5). Titanium, thanks to its excellent biocompatibility, permits good tissue integration (Keller et al. 1994; Quirynen et al. 1996). However, in low density bone the reported success rates and the amount of bone to implant contact with smooth implant surfaces are lower than in implants with rough surfaces (Fig. 6). Predecki et al. (1972) observed rapid bone growth and good mechanical adherence on an implant surface with an irregular surface state. Brunette, in 1988, found extensive cellular interaction in the presence of an irregular implant surface. Bowers et al. (1992), in a histologic study, confirmed a large increase of the attachment of bone cells on a rough surface. For Davies (1998), an adequate implant surface texture optimizes the biologic response of the bone (Figs 7a and 7b).

Since the beginning of the 1980s, various teams have tried to improve implant surfaces in order to improve the primary anchorage and the amount of bone to

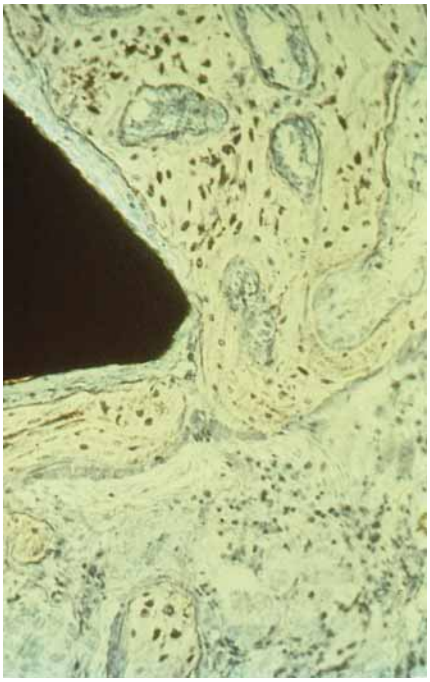

Fig. 6. Note the connective tissue on the implant surface. The absence of direct bone/implant contact results in implant mobility (magnification ×40).

implant contact (Buser et al. 1991; Gotfredsen et al. 1995). Different experimental studies showed good primary healing with the addition of a layer of hydroxyapatite onto the titanium (Thomas et al. 1987; Cook et al. 1992; Wong et al. 1995) (Fig. 8). Orenstein et al. (1998) obtained a success rate of 93.8% for 81 mobile implants at the original time of surgery. Among these 81 implants, the 54 coated with hydroxyapatite (HA) achieved a 100% success rate. In contrast, a failure rate of 19.5% was reported for the 27 machined surface implants. However these impressive results have been tarnished by the questionable long-term stability of HA. Some authors have reported peri-implant bone loss and a higher failure rate in direct relation to the implants with HA coating (Johnson 1992; Piatelli et al. 1995; Weehler 1996). Erosion of the surface of the HA layer has also been reported (Cheang & Khor 1996).

Surgical techniques intended to increase cortical anchorage

Brånemark et al. (1984) recommended cortical anchorage of the implant at the level of the sinus floor in order to improve the initial stability. In maxillary posterior sectors, we find mostly low density bone. The sinus membrane is, therefore, slightly raised with the implant. The consistency of this membrane normally permits its separation from the cortical bone without tear or perforation. A bicortical anchorage is thus obtained. Brånemark et al. (1984) reported the results of 69 implants which penetrated the sinus. The 2 to 5 year success rate of 25 implants was 88%. However, a decreased success rate (70%) from 5 to 10 years was reported for 44 implants.

In 1989, Tulasne proposed the use of pterygo-maxillary bone mass for positioning dental implants. The intracortical stabilization of an implant of length equal to or greater than 13 mm showed good results (Fig. 9). Tulasne (1992), Bahat (1992), Khayat & Nader (1994), Venturelli (1996) and Fernandez-Valeron & Fernandez-Velazquez (1997) showed high success rates (from 92% to 98%) with tuberosity and pterygo-maxillary implants. The majority of the complications observed with this surgical protocol are prosthetic ones (fractures of diferents components). Fernandez-Valeron & Fernandez-Velazquez, in 1997, proposed the use of osteotomes for the preparation of tuberosity implant sites. The primary anchorage of the implant is, thus, improved thanks to increased bone to implant contact.

Wide diameter implants

Many publications report high failure rates with standard implants in the presence of low density bone (Jaffin & Berman 1991; Friberg et al. 1991; Johns et al. 1992). In 1987, Langer developed the 5 mm diameter implants based on the basic concepts of osseous integration, i.e. the importance of the anchorage surface for better primary stabilization of the implant (Langer et al. 1993). The use of a wide implant may be considered if the width of the alveolar crest is greater than or equal to 8 mm (Davarpanah et al. 1995). The diameter of the body of the implant more easily permits bicortical (buccal/lingual) stabilization (Ivanoff et al. 1997). Using wide

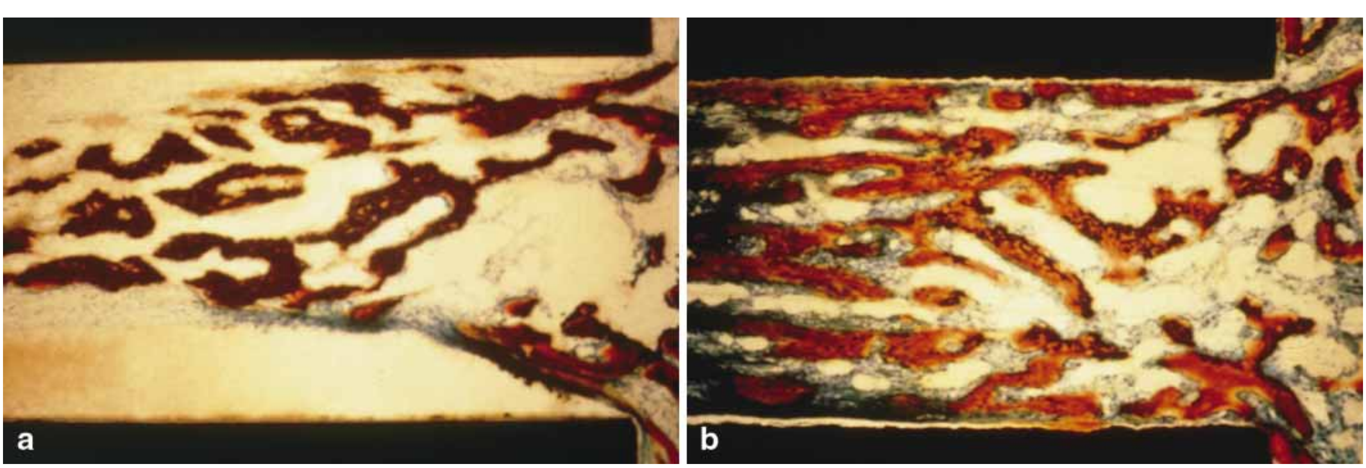

Fig. 7. Bone growth in titanium chambers (from Davies, 1998). a. Reduced bone formation and surface attachment is seen with machined surface. b. Complete bone growth is achieved with an acid-etched surface.

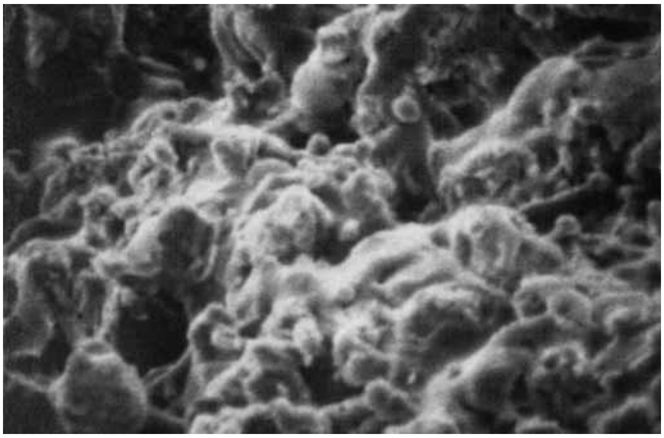

Fig. 8. Scanning electron microscope photomicrograph of a hydroxyapatite implant surface. Note the globular topography.

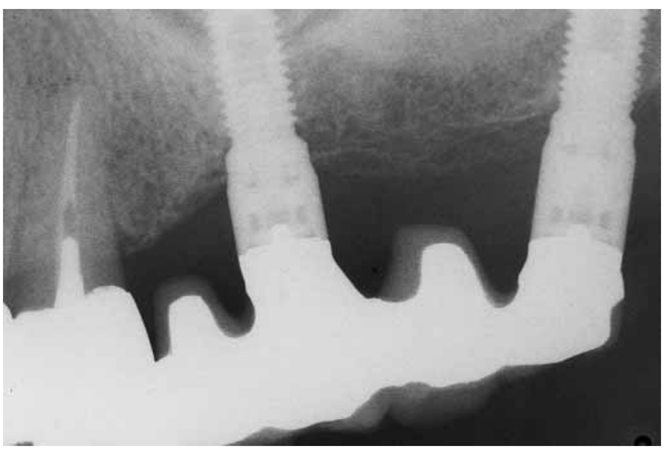

Fig. 9. Peri-apical radiograph of two maxillary posterior fixtures. Note the pterygo-maxillary position of the distal implant.

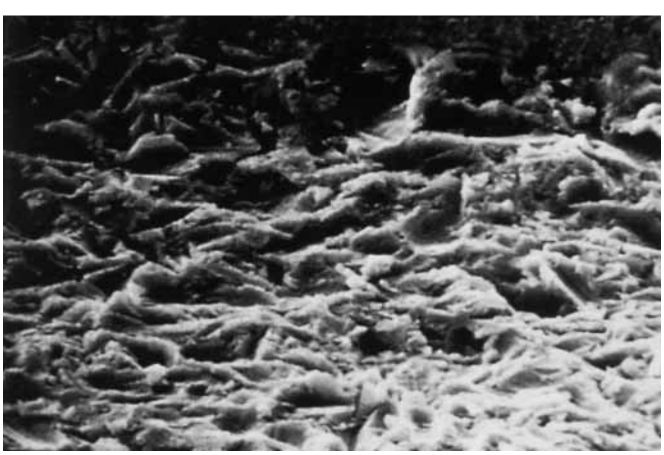

Fig. 10. Scanning electron microscope photomicrograph of a blasted implant surface. Note the cratered topography (magnification ×2000).

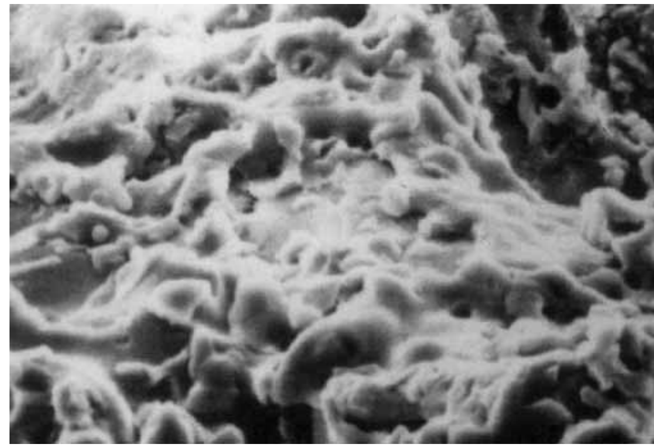

Fig. 11. Scanning electron microscope photomicrograph of a titanium plasma-sprayed surface. Note the globular topography (magnification ×2000).

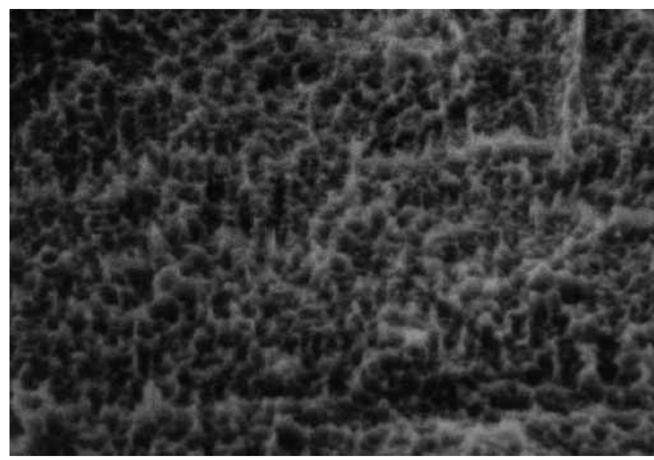

Fig. 12. Scanning electron microscope photomicrograph of acid-etched (HCL/H_2SO_4) surface. Note the regular distribution of small peaks and valleys (magnification ×2000).

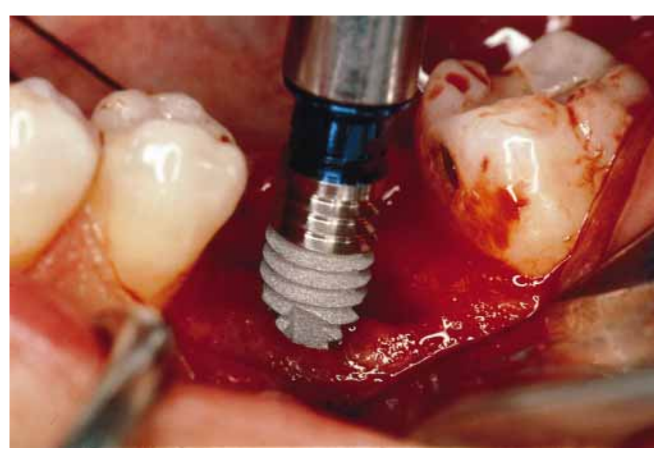

Fig. 13. Clinical view of a hybrid design implant surface (Osseotite™).

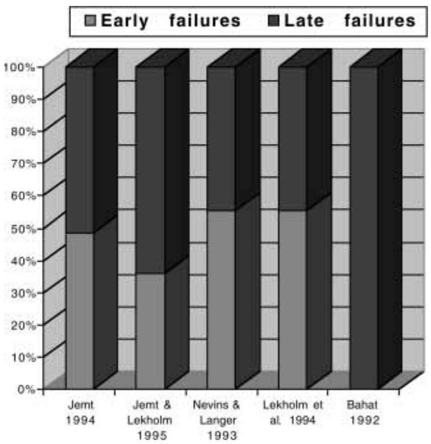

Fig. 14. Frequencies of early failures (before loading) and late failures (after loading).

implants enables the practitioner to increase initial stability in the presence of low density bone. However, some publications have described greater bone loss with first generation wide implants (Davarpanah et al. 1995, 1999; Renouard et al. 1999; Ivanoff et al. 1999). According to these authors, the design of the implant, a poor bone quality and inappropriate surgical technique are the principal causes of complications.

New therapeutic proposals

New surface textures

For the past decade, many researchers have worked on the development of new surface textures in order to improve initial implant stability and bone healing. Buser et al. (1991) analyzed the percentage of direct bone/implant contact for different surface states: sandblasted, hydroxyapatite, TPS (titanium plasma-sprayed) and acid-etched. The highest percentage of bone/implant contact is recorded with the surface treated by sandblasting and by acid etching (HCl/H_2SO_4) (Figs 10 to 12).

The TPS surface has been shown to increase the surface area available for osseointegration, and to enhance the rate of bone formation. It has undergone long-term clinical evaluation as part of the ITI system. The clinical studies have reported a high success rate (>93%) with TPS surface implants (Buser et al. 1992, 1997; Mericske-Stern et al. 1994; Wismeyer et al. 1995).

The commercially pure titanium layer is preserved by subtractive treatment of the surface: acid-etched or sandblasted. The probability of contamination of the surface and of the dissemination of micro-particles into the surrounding tissues is extremely reduced (Lacefield 1997). Experimental studies report extremely good results for surfaces etched with HCl/H_2SO_4 acid (Davies & Dziedzic 1996; Lazzara et al. 1999). The first clinical studies (Osseotite™ : implant surface etched with HCl/H_2SO_4 acid) have showed very high success rates (Sullivan et al. 1997; Lazzara et al. 1998; Grunder et al. 1999) (Fig. 13). Almost all the failures with this type of implant surface texture have been reported before loading. Grunder et al. (1999) reported, in a prospective multicenter study, a cumulative implant survival rate of 96.6% for 89 Osseotite™ implants placed in the posterior maxilla. The postloading implant survival rate at 28 months has remained at 100%. The authors emphasize the increase of prosthetic predictability with this type of implant surface. On the contrary, implants with smooth surfaces have significant failure rates after loading (Jemt 1994; Jemt & Lekholm 1995; Nevins & Langer 1993; Lekholm et al. 1994; Bahat 1992; Esposito et al. 1998) compared to surface modified implants (Lazzara et al. 1998; Grunder et al. 1999). Failures before loading are called early failures as opposed to late failures occurring after loading (Fig. 14).

A surface treated by sandblasting and acid etching (SLA) has been proposed by the Straumann Institute since the early 1990s. The titanium surface is first sandblasted with large particles causing a grossly rough surface which is secondarily acid-etched, forming a finely rough surface. The purpose of this surface texture is to improve the initial implant stability in low density bone and to maximize the quality of the bone-implant interface (Wilke et al. 1990). Numerous experimental studies have shown promising results with respect to bone healing (Cochran et al. 1988, 1996; Buser et al. 1991, 1998). Recently, Cochran presented the preliminary clinical results on ITI implants with SLA surface; 835 implants were placed in 371 patients. The healing time was reduced to 6 weeks on 549 implants. The success rate at one year was 99%. No failures were reported after prosthetic restoration (Cochran 1999).

The evolution of implant anatomy

The majority of implant systems offer a cylindrical fixture design, either screwed in or tapped into position. An increase in implant width, implant collar size, or root shape anatomy means an increase in bone to implant contact resulting in better implant stability. An original root form design proposed in 1974 (Frialit®-1) and modified in 1992 (Frialit®-2) permits a good adaptation within the alveolus (Fig. 15). This type of implant was initially designed for extraction sockets and low bone volume; its shape is appropriate to increase initial stability. Gomez-Roman et al. (1997) showed a 96% success rate at 5 years for implants immediately placed following extraction. However, no study of the use of this implant in low density bone has been published. Recently, Steri-Oss® proposed a screw-type root form implant (Replace™). This design favors initial anchorage thanks to the combination of the implant threads and a flared anatomy. The firm Implant Innovations® proposed an implant having a collar wider than a millimeter in relation to the implant body (Osseotite XP ™). This cervical anatomy permits better initial stability of the implant (Fig. 16). The association of this implant shape with a rough surface increases the implant anchorage surface by 30%. Longitudinal studies must confirm the clinical applications of these implants in type IV bone.

The Nobel Biocare® firm presented a new wide implant in 1996 (Wide Platform) in 5 and 5.5 mm diameters. An increase in implant width means an increase in bone to implant contact and a better implant stability (Fig. 17). A greater widening during surgical preparation may compromise the initial stability of the fixture in the presence of low density bone. It is, therefore, suggested that the implant should not be forced into position when adequate bone is not present (Wikstrom 1996). Jisander proposed implant modifications (Brånemark® system) for maximum initial stability in low density bone (Darle & Jorneus 1998). This new fixture (Mk IV) of-

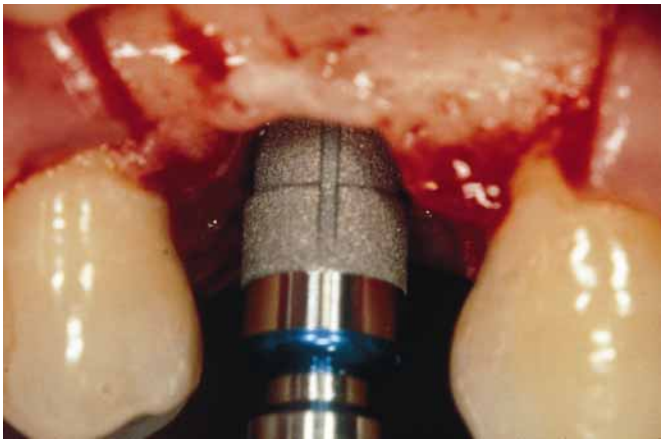

Fig. 15. Placement of Frialit®-2 implant. Note the gradually tapered implant design.

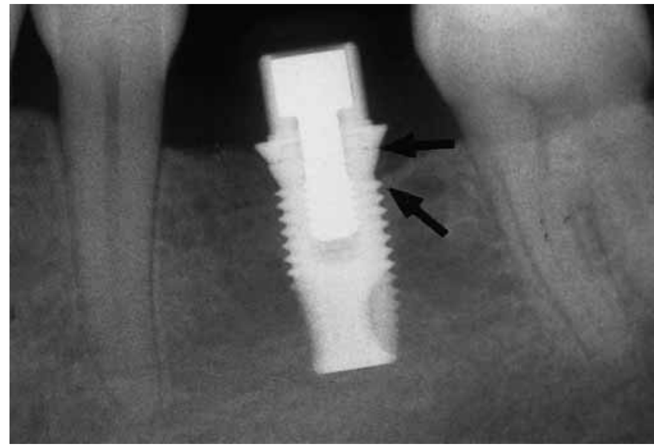

Fig. 17. Radiograph of a Wide Platform fixture (Nobel Biocare®). Implant diameter of 5 mm and smooth collar of 5.1 mm.

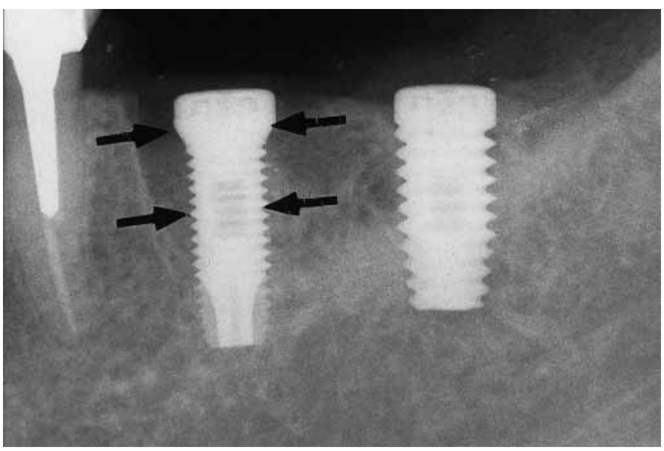

Fig. 16. Radiograph control after immediate placement of an Osseotite XP™ implant following extraction. Note the expanded platform implant design. The initial stability is increased because the flared coronal aspect engages the crestal bone.

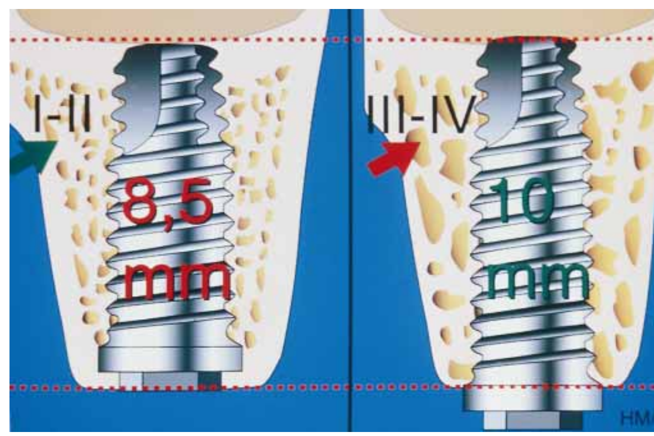

Fig. 18. Left: conventional implant positioning. Right: supra-crestal implant positioning allows a better primary stability by crestal engagement in low density bone.

fered a slightly conical anatomic form and a double-spiraled thread. These morphological characteristics permit the operator to achieve compression and progressive anchorage. The manufacturers advise that the forces exerted during insertion may be progressive. Too great a turning motion during insertion may cause collapse of the bone threading and the loss of initial implant stability. The first experimental tests with this fixture show an increased initial stability when compared to smooth and rough-surfaced implants (Darle & Jorneus 1998), however no clinical studies have yet been published using these new implant designs.

Bone condensation using osteotomes

The osteotome technique has been described by Summers in 1994. The objective of this method is to preserve all the existing bone by minimizing or even eliminating the drilling sequence of the surgical protocol. The bone layer adjacent to the osteotomy site is progressively compacted with various bone condensers (osteotomes). This will result in a denser bone to implant contact. This improved bone density helps to optimize primary implant stability in low density bone. Summers reported a 96% success rate for 143 press-fit implants placed in soft bone in 55 patients (11 to 27 months post-loading). Hydroxyapatite-coated and TPS-coated implants were used in this study. This technique seems interesting for low density bone, however, no long-term or multicenter studies are reported in the literature.

A submerged implant with its collar in a supra-crestal position

This surgical option recommends the placement of the implant collar of submerged implants in a supra-crestal position (Davarpanah et al. 1999, 2000a & b). The surgical protocol is similar to that of submerged implants just until the last drilling of 3 mm or 3.15 mm depending

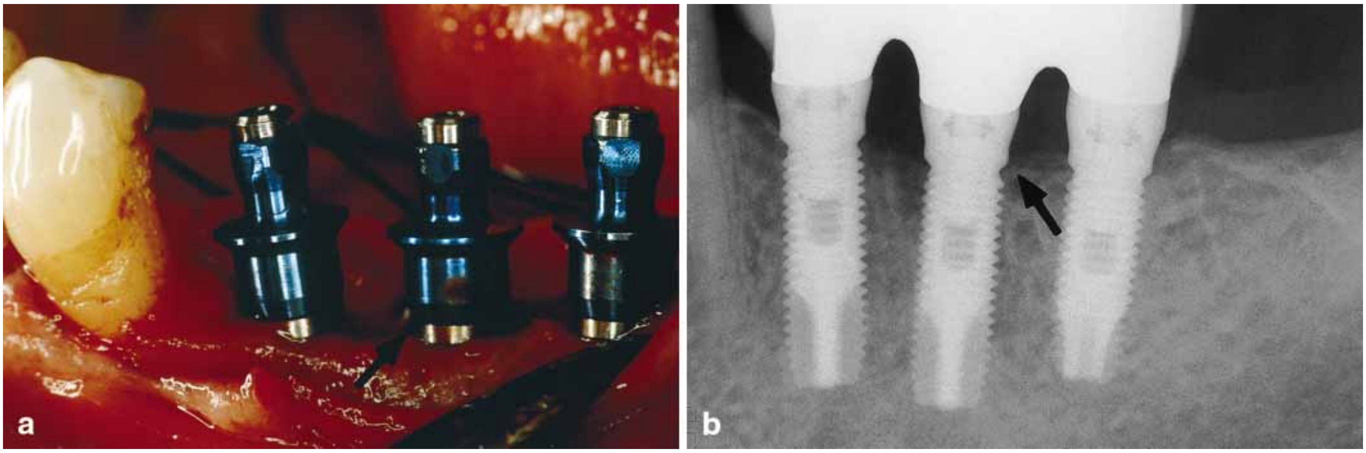

Fig. 19. a. Clinical view of three 3i Osseotite™ implants in a supra-crestal position. b. Radiographic control after one year implant loading: the bone level is stable at the first thread.

on the bone quality. The cervical flaring (countersink) of the implant site is not performed. As a matter of fact, countersinking, especially in type III and even more in type IV bone, jeopardizes the cortical alveolar bone thickness. Therefore, the absence of coronal flaring of the implant site will optimize the initial implant stability thanks to a blockage of the collar in the cortical bone (Fig. 18). The association of a wider collar implant (Osseotite XP ™) increases primary stability even more because of better crestal engagement (Figs 19a and 19b). This supra-crestal position of the collar also permits an improvement in the clinical crown to implant ratio. The supra-crestal positioning of the implant collar limits the bone loss at the cervical level and permits the use of a longer implant. The implant length is of utmost importance for initial stability and improved success rates (van Steenberghe et al. 1990; Wyatt & Zarb 1998). Conventional positioning of the implant (countersinking) can sometimes compromise initial stability in the presence of insufficient or limited cortical bone thickness.

Recommended protocol for implant placement in low density bone

Surgical preparation

- Precise surgical preparation of the implant site is of utmost importance, especially for wide diameter implants.
- The implant direction should be respected during the various drilling sequences.
- For the widest burs, it is recommended not to drill to the total implant length.
- Bone condensation with osteotomes will increase the percentage of bone to implant contact.
- Light forces should be exerted during implant insertion.
- Minimal or no countersinking is advised.

Implant design

- The choice of the implant design should aim at increasing the surface of bone to implant contact.
- When the bone volume is sufficient, a wide diameter implant and wide collar are recommended.

Implant surface texture

- Rough implant surfaces are advocated not only to increase primary stability but mainly to improve bone healing.
- The highest percentage of bone/implant contact has been reported with a sandblasted and acid-etched (HCl/H_2SO_4) implant surface texture.

Conclusion

Primary implant stability is a fundamental factor in obtaining osseointegration. Clinical and radiographic evaluation of bone quality and of primary stability remains essential. Early surgical approaches aimed at improving the amount of bone to implant contact. New implant designs, surface textures and surgical protocols have increased predictability in poor bone quality. Longitudinal studies are necessary to confirm the effectiveness of these new proposals.

Résumé

La stabilité initiale d'un implant est un des critères fondamentaux pour obtenir l'ostéointégration. Un ancrage primaire adéquat est souvent difficile à obtenir en présence d'un os de faible densité (Type IV). Différentes suggestions chirurgicales qui ont été avancées dans les années 1980 ont été essayées afin d'obtenir une intégration osseuse optimale dans un os de pauvre qualité. Elles offraient des résultats satisfaisants à court terme. Récemment les résultats des innovations tant chirurgicales que technologiques ont donné suite à des nouvelles propositions thérapeutiques qui ont montré des résultats très intéressants dans leurs études initiales.

Zusammenfassung

Die Primärstabilität des Implantates ist eine der grundlegenden Anforderungen zur Erreichung einer Osseointegration. Die Erreichung einer ausreichenden Primärstabilität ist bei Knochen von geringer Dichte (Typ IV) oft schwierig zu erreichen. Zur Erreichung einer optimalen Osseointegration bei unzureichender Knochenqualität wurden in den Achzigerjahren verschiedene chirurgische Vorschläge publiziert. Sie zeigten alle zufriedenstellende Kurzzeitresultate. In letzter Zeit zeigten neue therapeutische Vorschläge, resultierend aus chirurgischen und technischen Neuerungen, sehr interessante Erfolge, zumindest in den ersten Phasen der klinischen Studien.

Resumen

La estabilidad inicial del implante es un criterio fundamental par obtener osteointegración. A veces es dificil lograr un anclaje primario en hueso de baja densidad (Tipo IV). Se han avanzado varias sugerencias quirúrgicas en los 80 que intentaban lograr una integración óptima en hueso de baja calidad. Estas ofrecían resultados satisfactorios a corto plazo. Recientemente, como resultado de las innovaciones quirúrgicas y tecnológicas, nuevas propuestas terapéuticas han mostrado resultados muy interesantes en sus estudios iniciales.

要旨

インプラントの初期固定は、骨性統合を達成するための基本的要件の一つである。低密度の骨(タイプ４）においては適切な初期固定を達成するのが難しいことが多い。質の劣る骨において最適な骨性統合を達成するために１９８０年代に様々な術式が開発されたが、これらは満足のゆく短期成績を達成した。近年の術式と技術革新の結果、新しい治療上の試みは初期研究において非常に興味深い結果を示している。

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