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Modern implant dentistry based on osseointegration: 50 years of progress, current trends and open questions

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In the past 50 years, implant dentistry has evolved from an experimental treatment to a highly predictable option to replace missing teeth with implant-supported prostheses. It is a treatment modality widely used in daily practice for fully and partially edentulous patients because modern implant therapy offers not only significant functional and biologic advantages for many patients when compared with conventional fixed or removable prostheses, but also yields excellent long-term results, as documented by numerous 10-year studies with success and survival rates above 95% (46, 80, 89, 98). This breakthrough in oral rehabilitation was initiated 50 years ago by the discovery that implants made of commercially pure titanium could achieve anchorage in the bone with direct bone-to-implant contact. The most important pioneer of modern implant dentistry was Professor P. I. Brånemark from the University of Gothenburg (Sweden) who performed the first preclinical and clinical studies in the 1960s (33). Later, he termed this phenomenon osseointegration (32), which is today a widely accepted term. In the late 1960s, the second pioneer, Professor André Schroeder from the University of Bern (Switzerland), started to examine the tissue integration of various implant materials, and his group was the first to document direct bone-to-implant contact for titanium implants in nondecalcified histologic sections (177). A few years later, he also reported as the first one about the soft tissue reactions to titanium implants (179). Both pioneers were leading a team that performed numerous preclinical and clinical studies to establish the scientific basis for modern implant dentistry. The group in Sweden became known as the Brånemark team, with high-profile team members such as Tomas Albrektsson, Ragnar Adell, Ulf Lekholm and Torsten Jemt; whereas André Schroeder established, in 1980 in Switzerland, the International Team for Implantology, which has become, in the intervening 35 years, the world's largest association in implant dentistry, with more than 15,000 members and fellows in approximately 100 countries worldwide. Initially, the research teams in Sweden and Switzerland did not know about each other as they published their early studies only in local journals in their respective countries and they worked independently of each other.

1965 to 1985: the scientific quest for osseointegration and its clinical application

Until the mid-1980s, only basic surgical guidelines had been established for the predictable achievement of osseointegration. These guidelines included a low-trauma surgical technique for implant bed preparation to avoid overheating of the bone during preparation, implant insertion with sufficient primary stability and a healing period of 3–6 months without functional loading (3, 32, 179). Both research teams agreed on these basic principles of implant surgery. However, there were differences concerning two other important aspects – the healing modality and the implant surface. The Brånemark team used titanium screw-type implants with a machined surface, which was rather smooth, whereas the Schroeder International Team for Implantology used titanium implants of various shapes with a titanium

plasma-sprayed surface, which was quite rough and microporous. In addition, Brånemark required submerged healing of the implant, whereas Schroeder favored nonsubmerged, transmucosal healing because the prototype implants tested were all made as one-piece implants with the abutment being an integral part of the implant. Both aspects caused, in the 1990s, heated debates at professional congresses.

Both research teams worked closely with an industrial partner because they needed the expertise of proper development and engineering, precise manufacturing, marketing and sales. It is remarkable that these initial partners have, in the last 30 years, developed into the most famous brands and successful companies in implant dentistry, namely Nobel Biocare (initially called Nobelpharma) and Straumann. Both are examples of an impressive success story, achieved through translational medical research, input of science-focused clinicians worldwide and professional entrepreneurship during the past 50 years.

In the initial phase of clinical testing, Brånemark used titanium implants primarily in edentulous jaws to support fixed dental prostheses with the goal to improve chewing comfort and the quality of life for these patients. The clinical results up to 15 years of follow up were very promising, in particular in the edentulous mandible (1, 32). The International Team for Implantology used the prototype implants with a titanium plasma-sprayed surface, not only in fully edentulous mandibles but also in partially edentulous patients with shortened dental arches and single tooth gaps (136, 145, 178).

During this developing phase in the 1970s and 1980s, other implant materials or prototype implants were clinically tested. A prominent implant in Germany was the ceramic Tuebingen implant made of aluminum oxide (181). Another prominent German implant system was the titanium, nonthreaded IMZ implant system with a titanium plasma-sprayed surface (15, 131). The American Core-Vent implant system utilized a titanium aluminum vanadium alloy (158, 165) and was quite prominent on the market.

In the second half of the 1980s, there was a marked shift in the dental implant market to the use of commercially pure titanium as the implant material of choice (187–189), and the threaded solid screw-type implant became the preferred implant shape. This evolution was induced by a famous and highly cited paper by Albrektsson et al. (7), which reviewed the efficacy of dental implant systems available at that time. In addition, the one-piece prototype implants first used by Schroeder's International Team for Implantology in the 1970s were further developed into two-piece implants to offer more prosthetic flexibility with various abutments (193) but keeping the basic concept of a tissue-level implant for a nonsubmerged healing modality in healed sites (55). This evolution meant that, by the end of the 1980s, the leading implant systems offered mainly two-piece titanium screw-type implants with either a machined or a rough titanium plasma-sprayed surface.

1985 to 2000: major progress in the field of implant dentistry

The next phase in implantology started in the mid-1980s, when implant therapy expanded into partially edentulous patients. The first clinical publications appeared around 1990 and were encouraging in terms of implant-related outcomes (53, 54, 147, 174, 197). Since then, partially edentulous patients have become the dominant patient group, and in some competence centers, they currently represent more than 90% of all implant patients (24, 36). Consequently, the growing demand to replace lost teeth by not only functional but also esthetically pleasing implant-supported restorations became an important challenge. Industry answered by producing a larger number of prosthetic implant components, such as angulated abutments, and esthetic single-tooth and cementable abutments. Clinical research was pushed to improve the condition of soft and hard tissues. This esthetically driven demand was answered by the development of bone-augmentation procedures to overcome local bone deficiencies in potential implant sites. The best-documented surgical techniques for bone augmentation were guided bone regeneration utilizing barrier membranes and sinus floor elevation (2). The guided bone-regeneration technique was initiated with preclinical studies around 1990 (51, 75, 76, 172). In the same period, the first case reports and short-term clinical studies were published to document various applications of the guided bone regeneration technique in patients (17, 40, 74, 128, 143, 159). During the 1990s, surgical modifications were implemented to improve the predictability of the guided bone regeneration technique and to reduce the risk of complications. This included improved incision techniques, the utilization of fixation devices to stabilize the membranes and the application of bone grafts to support the membranes (43, 128). Later, the utilization of resorbable barrier membranes became increasingly more popular, in particular noncrosslinked collagen membranes, as

they were able to reduce the number of surgical interventions and the rate of complications (103, 110, 112, 214). The sinus floor elevation technique was first introduced during the 1980s (30, 195) with the lateral window technique. In the 1990s, a second technique was presented, which is often called the osteotome technique using a transalveolar approach (191). In 1996, the first sinus consensus conference was held by the Academy of Osseointegration, presenting acceptable clinical results (115).

In the 1990s, a paradigm shift took place in the field of implant surface technology. As mentioned above, the first 20 years of the implant market was dominated by two surfaces: the rather smooth machined surface; and the rough, microporous titanium plasma-sprayed surface. This new development was initiated by a preclinical study at the University of Bern by Buser et al. (52). They examined the influence of surface characteristics on bone apposition to five different titanium surfaces. The best bone apposition among titanium surfaces was found for a surface produced with sandblasting using a large grit and an acid-etching technique. A hydroxyapatite surface showed the highest bone-to-implant contact values but also yielded significant signs of resorption. Therefore, the hydroxyapatite surface was not the first choice and its clinical application is currently not recommended. The sandblasted and acid-etched surface, which was moderately rough or microrough, also showed significantly increased removal torque values when compared with implant surfaces classified as smooth or rough (49, 50). Similar findings were found by other groups for surfaces with various sandblasting techniques alone, both in histomorphometric and in removal torque value studies (207–209), and for implant surfaces produced by a dual-acid technique in removal torque value studies (132, 133). At this time also the original Brånemark implants became available with a moderately rough, microporous surface produced by anodic oxidation (141), and was marketed as the TiUnite surface. Preclinical studies have shown a markedly stronger bone response to TiUnite surfaces than to machined control surfaces (213). These preclinical studies triggered heated debates in the late 1990s but also initiated studies of these new titanium surfaces, which are most often called microrough or moderately rough surfaces. Currently, the microrough implant surfaces of various brands are accepted as the surfaces of first choice (37, 206). Two of these new microrough surfaces were intensively tested in an early loading protocol after 6–8 weeks of healing up to 5 years of follow up (28, 67, 190). This early loading has become a well-documented loading protocol for partially edentulous patients, indicating a clear reduction of healing periods compared with the original healing periods proposed by Brånemark and Schroeder in the 1970s (204). In the same decade, the immediate loading protocol became well documented, especially for fully edentulous patients. The protocol was first tested with implant-retained overdentures in the edentulous mandible (14, 146) and was later introduced for fixed implant-supported prostheses (167, 175, 176). The reduction in healing period was an important development to increase the attractiveness of implant therapy and was primarily facilitated by these improved microrough implant surfaces. Currently, the clinical outcome for immediate loading in fully edentulous mandibles and maxillae is comparable with that for conventional delayed loading (79). The authors reported a failure rate of 0–3.3% for the edentulous mandible and a failure rate of up to 7.2% for the maxilla. In the early 1990s, another debate raised the question of whether an implant must be submerged or not during healing in order to achieve osseointegration with high predictability. Successful tissue integration of nonsubmerged titanium implants with a titanium plasma-sprayed surface was demonstrated in preclinical and clinical studies (39, 48, 54, 202, 203). When this was confirmed in clinical studies using Brånemark-type implants (18, 19, 88), this debate came to an end around the Millennium change (95). Since then, there is agreement that both healing modalities can be applied in daily practice depending on the clinical situation. When possible, a nonsubmerged healing modality is utilized, which is advantageous for the patient because it eliminates surgical intervention and reduces cost and morbidity. On the other hand, additional bone or soft-tissue regenerative procedures, or certain risk patients, may benefit from a submerged healing period without functional load.

Another attempt to ease implant therapy for the patient involved efforts to reduce the time between tooth extraction and implant placement. The concept of immediate implant placement was first utilized in Germany (181) and was then adopted around 1990 (17, 143, 159). The 1990s was the trial-and-error phase of immediate implant placement, with numerous short- and mid-term studies primarily presenting survival data (13, 16, 31, 96, 100, 135, 140, 210). The topic of implant placement postextraction has been debated at all major implant congresses ever since and is discussed below in more detail.

2000 to 2010: the fine-tuning phase in implant dentistry

After the change of the Millennium, 15 years of major developments and significant progress came to an end, in particular in the surgical field, and a new phase started with several fine-tuning efforts. The dental research community tried to improve implant therapy further with the goal to optimize the so-called primary and secondary objectives of implant therapy (38).

The primary objectives of implant therapy are twofold: first, to achieve successful treatment outcomes from a functional, esthetic and phonetic point of view with high predictability and good long-term stability; and, second, to have a low risk of complications during healing and during the follow-up period. These aspects are most important for patients because they want to know what long-term prognosis they can expect and what risks are involved with different treatment proposals. Treatment outcomes are primarily measured by assessment of implant survival and success rates but also increasingly according to patient-centered outcomes (78).

The secondary objectives of implant therapy include the fewest possible number of surgical interventions, low pain and morbidity during healing, short healing periods, short overall treatment time and acceptable good-effectiveness. These objectives are also very important for patients but they are clearly of lower priority when compared with the primary objectives. In the past 16 years, significant progress has been achieved with these fine-tuning efforts, although the steps of progress were clearly smaller and incremental and related to the ethically guided strive for minimal risks for patients.

Significant progress was achieved in relation to esthetics. This became a topic of increasing interest in the mid-1990s (20) and came to the forefront after the Millennium change at every implant conference offered by national or international associations. Several improvements in implant components or surgical and prosthetic protocols were presented, such as a better understanding of the correct three-dimensional implant positioning in relation to the esthetic outcomes (47, 94, 99). Another attempt was made with improved manufacturing of titanium implants using the concept of platform switching (144). This concept has been adopted by most of the major implant manufacturers because it was claimed that this implant design would be more effective at maintaining peri-implant bone levels in the crestal area. This was confirmed in some clinical studies and systematic reviews (12, 44, 111); however, a recent randomized controlled trial shows that platform switching is only effective when the mucosal thickness allows establishment of a biologic width (198). In the prosthetic field, the development of zirconia abutments had a major impact (8, 97, 160, 166, 168). In addition, the importance of implant esthetics has also been underscored with the development of esthetic parameters to judge esthetic outcomes (21, 91). The whole spectrum of implant esthetics is critically reviewed in this volume of *Periodontology 2000* and is discussed in the paper by Cosyn et al. (72).

Treatment protocols were also improved in the field of postextraction implant placement, originally triggered by clinical and preclinical studies examining postextraction ridge alterations (10, 11, 180). These studies provided the basis for a much better understanding of the tissue biology in postextraction sites. An update of these aspects are comprehensively provided in this volume of *Periodontology 2000*, with a review paper by Chappuis et al. (56) including the aspects of socket grafting and ridge-preservation techniques. The expanded knowledge about these biologically driven ridge alterations and the severe vertical bone resorption observed in postextraction sites with a thin-wall phenotype in the anterior maxilla of patients (59) has helped to increase our understanding of the various causes of esthetic complications with severe mid-facial recession of the mucosa in immediate implants (60, 63). Since 2003, this topic has been debated and analyzed at three consecutive International Team for Implantology consensus conferences where the classification of treatment options was defined, risk factors for mucosal recessions at immediate implants were identified and selection criteria for the potential treatment options with immediate, early or late implant placement were described (61–63, 65, 102, 155). A recent, 5-year study demonstrated that around single, immediately restored implants, the mid-facial recession, the mid-facial contour and the alveolar process deficiency deteriorate over time, and close to 50% of the cases showed esthetic issues despite treatment by experienced clinicians (71). This emphasizes the importance of proper case selection and risk assessment, and underscores the importance of proper long-term documentation of at least 5 years before a clinical protocol can be objectively judged. This important topic, in particuar in esthetic sites, is discussed in the review paper by Buser et al. (41) in this volume of *Periodontology 2000*.

To compensate for postextraction bone resorption, bone augmentation must be performed in the majority of esthetic implant sites, in particular on the facial aspect (47, 99). In sites with minor bone deficiencies, the use of a connective tissue graft can be used as an alternative to increase the buccal soft tissues (70). This localized bone augmentation is performed using the guided bone-regeneration technique, which was further fine-tuned after the Millenium change. Besides the change to resorbable collagen membranes (104), preclinical research started to focus on bone grafts and bone subsititutes for guided bone-regeneration procedures. These bone fillers not only mechanically support barrier membranes to reduce the risk of membrane collapse during healing, they also have biologic properties, such as osteogenic potential to activate new bone formation, and a high or a low substitution rate, which will influence the stability of the augmented bone over time (45, 116–118, 121). A bovine bone filler demonstrated a low-substitution rate and is widely used, not only for contour augmentation in early implant placement (42, 69) but also for internal augmentation in immediate implant placement (64, 70). A similar discussion on bone grafts and bone substitutes also took place for sinus floor elevation. For this bone augmentation technique, numerous combinations have been examined and used in patients, including autografts alone, allografts alone, xenografts alone or combinations of thereof, which is often called a composite graft (35, 120). A recent preclinical study confirmed previous results of bone filler research for guided bone regeneration and demonstrated that autografts increased the bone-to-implant contact at 12 weeks of healing and that a bovine-derived low-substitution filler showed much better volume stability when compared with allografts (122, 124). The combination with autografts does not improve the long-term results of implants (123) but it helps to reduce the healing period (137). It was also recommended to perform sinus floor elevation without any application of bone fillers in well-selected patients (150). An update on sinus floor elevation procedures with different treatment approaches, the respective selection criteria and long-term data are provided in a narrative review by Lundgren et al. (151).

Another important field of improvement was achieved in the area of preoperative radiographic examination using the new three-dimensional cone-beam computed tomography technology, which was first described in the late 1990s (156). This technology quickly replaced the dental computed tomography that was used in implant dentistry during the 1990s (182). The main concern with dental computed tomography was radiation exposure in patients, which prevented its widespread application in daily practice (87). Thus, rather conservative guidelines were given for the utilization of dental computed tomography in implant patients by a European Association of Osseointegration workshop (105). The new cone-beam computed tomography technology offered improvements over dental computed tomography, not only concerning image quality but also concerning radiation exposure (27, 101, 148, 149). The technological progress of cone-beam computed tomography and the much reduced radiation exposure have led to considerably wider application of this technology in daily practice (23) and less conservative guidelines have been formulated by the European Association for Osseointegration (106). Up-to-date information on cone-beam computed tomography is offered in the review paper by Bornstein et al. (26).

The advent of cone-beam computed tomography was also an important basis for the progress in digital implant dentistry, which has influenced both surgical and prosthetic aspects of implant dentistry. In the surgical field, increasingly sophisticated surgical stents were created, which could be used for computer-assisted implant surgery. These computer-assisted implant surgical techniques were often recommended for a flapless surgical approach (34, 90). In the prosthetic field, the first steps toward computer-aided design and computer-assisted manufacturing were made. In 2008, these initial developments were critically scrutinized at the 4th International Team for Implantology Consensus Conference. A systematic review in the surgical field reported acceptable precision of computer-assisted implant surgery but only short-term data were available (129). The status concerning computer-aided design and computer-assisted manufacturing procedures was less positive. A systematic review in the prosthetic field concluded that clinical studies on the use of computer-aided design and computer-assisted manufacturing techniques were too preliminary and underpowered to provide meaningful conclusions regarding the performance of abutments/frameworks designed using these manufacturing procedures (130).

In this decade, the technique of resonance frequency analysis was extensively examined in clinical studies. Originally developed in the mid-1990s by Meredith et al. (153), the resonance frequency analysis technique was significantly improved in 2004 and 2009, and hence has provided clinicians with an objective diagnostic tool to assess implant stability at

any stage during implant therapy and follow up. The resonance frequency is measured using a transducer and is translated into an implant stability quotient value on a scale of up to 100 implant stability quotients. The implant stability quotient value reflects the micro-mobility of the implant (164), which in turn is determined by factors such as bone density, surgical technique, implant design and healing time (184). A predetermined implant stability quotient 60 and 70 has been used as criterion for using immediate or early loading protocols in several studies (25, 137, 162, 163). Although numerous studies have shown the clinical value of the resonance frequency analysis technique to provide relevant information on the state of implant integration, no consensus guidelines have yet been presented on how to use the resonance frequency analysis technique in daily practice.

In the field of biology, there was a hype in the early 2000s to use platelet-rich plasma, which was triggered by a publication of Marx et al. (152) for bone grafting with maxillofacial surgery. It has been speculated that the stimulating effect of platelet-rich plasma was a result of the accumulation of autogenous platelets, providing a high concentration of platelet growth factors with a well-documented impact on bone regeneration (161, 186). A large number of platelet-rich plasma centrifuges were sold, pushed by the marketing efforts of the companies involved. A few years later, this hype ended abruptly when preclinical and clinical studies could not provide evidence that platelet-rich plasma was, in fact, able to accelerate osseointegration (119, 196, 205).

2010 and beyond: current trends and open questions

Compared with the era of introduction of dental implants in clinical practice half a century ago, implant survival is now highly predictable. Several clinical papers reporting on 10-year clinical outcomes with contemporary modern surface-modified implants revealed an implant survival rate of more than 95% and that less than 5% of implants are diagnosed with purulent infection or peri-implantitis (4). Similar results were reported by a few studies with up to 23 years of follow up (57, 83, 199). Despite the favorable clinical results, peri-implantitis has become one of the largest controversies in recent years. Suggestions by professional boards of periodontists that the incidence of biologic complications, and more specifically of peri-implantitis, may be up to 50%, has shaken the dental community. There is a lack of consensus regarding which types of clinical and radiographic parameters should be used to define peri-implantitis. The paper by Coli et al. (68) critically appraises the literature discussing the topic of peri-implantitis and revisited some papers in the context of diagnostic methodology and disease thresholds. It is obvious that the high prevalence of peri-implantitis reported by some authors is related to a scientific flaw that holds a certain risk of damage to the reputation of implant dentistry but also may lead to overtreatment of a 'so-called disease'. On the other hand, peri-implantitis may be a real clinical challenge that, of course, needs attention whenever diagnosed properly. In this context, the paper by De Bruyn et al. (77) points to patient risk factors for peri-implantitis, such as smoking and periodontal disease, in this volume of *Periodontology 2000*. In smokers with a history of periodontal disease, implant treatment seems to be prone to additional bone loss, as confirmed in a recent 9-year follow-up study (201).

Since the days of the founding fathers, the choice between predominantly screw-retained or cement-retained prosthetic restorations has been a matter of debate. The quest for improved esthetic outcomes and the practicality of digitally designed abutments have guided clinicians more toward cementable options. On the other hand, recent suggestions that cement remnants may induce peri-implantitis (211) counteract this evolution. The paper by Wittneben et al. (212), in this volume of *Periodontology 2000*, reviews the recent literature in this respect. It provides clinical guidelines for choosing the retention system appropriate for the patient on an individual basis and takes feasibility and complication risks into account.

The cause of crestal bone loss is another unanswered question and is heavily debated. It is mainly accepted that crestal bone loss at dental implants during the first year of loading is an inevitable phenomenon and is generally looked upon as an adaptive response to surgical trauma and loading (1). The amount of bone loss may differ according to the implant design and the location of the implant abutment interface (108, 109), but most types of implant show similar and minimal annual bone loss thereafter, based on average values (126, 142). However, if making a frequency distribution of the bone loss in a patient population, some implants will show more bone loss than others and a few implants will even show continuous loss of bone over time. It is, of course, important to be able to identify implants showing continuous bone loss as a result of the risk for poor esthetics, discomfort and failure. Long-term

studies on modern implant designs have shown that implant failure per se is rare, often being below 5%, and that the primary reason for implant failure is usually other than continuous marginal bone loss (4, 82). The reasons for marginal bone loss are not fully understood and are currently a matter of debate (4, 6). Some authors look upon marginal bone loss as a biofilm-mediated process that is similar to periodontitis and have suggested the use of periodontal indices to diagnose peri-implantitis (139). Other authors look at osseointegration as a balanced foreign-body reaction. Therefore, it has been suggested that marginal bone loss may also be influenced by factors modulating the immunologic balance, such as implant hardware, patient characteristics (including medication) and nonoptimal surgery and prosthetics. These potential causes are discussed in the two review papers by Albrektsson et al. (5) and Bosshardt et al. (29), the latter also providing a histologic update on osseointegration of titanium and zirconia implants.

A strong trend in implant dentistry is the increasing utilization of digital technology, particularly in the prosthetic field. The impressive progress with treatment planning software and with computer-aided design and computer-assisted manufacturing technology by the MedTech industry has simplified and improved the workflow of digital implant therapy and fixed prosthetic dentistry. Making a digital impression by using an intra-oral scanner may help to overcome errors that occur during conventional impression taking and pouring of stone models because the virtual model used by the computer-aided design software is created almost immediately using the data of the intra-oral scanner. Computer-guided milling further completes the procedure in a cost-beneficial way. Although many studies demonstrate a significant improvement in the accuracy of computer-aided design and computer-assisted manufacturing compared with conventional cast frameworks, much depends on the workflow from an impression procedure to the technical implementation during manufacturing of the prosthesis (200). The state of the art of digital implant dentistry was analyzed at the 5th International Team for Implantology Consensus Conference in 2013 in two systematic reviews, demonstrating clear progress since 2008 (130, 194). In the present volume of *Periodontology 2000*, further progress since then, and the currently feasible digital workflow and technical pros and cons, are reviewed by Joda et al. (127). In the surgical field, the current state of the art is critically reviewed in the paper by D'haese et al. (73). It is still unknown as to how fast, and to what extent, these digital techniques will achieve widespread application in private offices.

Another trend is that implant patients have become increasingly older since the arrival of the large birth cohorts of the so-called baby-boomer generation in dental practices in the western world. Consequently, the therapeutic strategies need to be adapted for elderly patients considering the special characteristics of this age group, especially medical risk factors, functional impairment and the possible onset of dependency and frailty (157). In implant surgery, it is important to minimize the morbidity for elderly patients. All these medical, surgical and prosthetic aspects have been scrutinized in the review paper by Schimmel et al. (173).

In the past 10 years, ceramic implants seem to be making a comeback, after their first clinical applications in the 1960s and 1970s. The first attempts to introduce aluminum oxide implants (169, 181) were not successful because at the end of the 1980s, commercially pure titanium implants became the material of choice in implant dentistry. The new trend in ceramic implants is based on zirconium dioxide (also known as zirconia) implants and successful preclinical testing (58, 92, 93, 170). A recent systematic review on clinical short-term studies with zirconia implants documents the potential of this interesting material (107). It seems as if the current preclinical and clinical documentation of zirconia implants are comparable with those of commercially pure titanium implants with modern microrough surfaces first reported approximately 15 years ago. The current status and potential advantages of zirconia implants are critically reviewed by Cionca et al. (66). It is as yet unknown whether it is possible for zirconia implants to become a valid alternative implant material to commercially pure titanium. Such a development would require information from long-term studies, similar to the existing data available for commercially pure titanium with microrough surfaces, and further progress of implant companies in the manufacturing of two-piece zirconia implants allowing the placement of screw-retained prostheses.

In recent years, the use of platelet-rich concentrates has again gained momentum in the dental field as an autologous source of growth factors. Not only platelet-rich plasma, but also platelet-rich fibrin and variations thereof (leukocyte-platelet-rich fibrin, fibrin-platelet-rich fibrin, etc.) have been examined by various groups *in vitro* (22, 84, 85, 171, 185). However, very little clinical documentation is currently avail-

able, and clear evidence for any beneficial effects on bone formation in postextraction or in peri-implant sites are still lacking (9, 81, 113, 192). The next few years will show if this interesting technique of platelet concentration will live up to its expections and produce a clinical breakthrough in the daily practice of implant surgery.

One increasing complication around osseointegrated implants in function is the development of peri-implant mucosal recessions. Despite the fact that, in most cases, mucosal recessions do not significantly influence long-term implant maintenance, their presence can affect the esthetic outcome and patient satisfaction. Several factors, such as the thickness of hard and soft tissues surrounding the osseointegrated implant, incorrect implant positioning (60) and/or the quality of prosthetic reconstructions, appear to play a role in the etiology of mucosal recessions. Owing to the increase in the number of implants placed worldwide, it can be anticipated that in the near future, the occurrence of mucosal recessions will also increase. The paper of Sculean et al. (183) in the current volume of *Periodontology 2000* critically appraises the literature regarding recession coverage. At present, the treatment possibilities for the coverage of peri-implant soft-tissue recessions are very limited and it is indicated that only shallow peri-implant mucosal recessions (e.g. up to 2 mm) may be successfuly treated by certain surgical techniques, including the use of subepithelial connective tissue graft or guided bone regeneration; no data support the possibility of covering deep and large peri-implant mucosal recessions.

Another ongoing debate is who should treat implant patients, and, in particular, who should perform implant surgery. The original approach of the Brånemark group in the 1970s and 1980s was that only surgical specialists were allowed on training courses in implant surgery. Thus, surgical specialists (oral and maxillofacial surgeons and periodontists) dominated the US market for at least 20 years. In Europe outside Sweden, for example in Switzerland and Germany, general practitioners were involved more in the early phase of modern implant dentistry with osseointegrated implants as postgraduate programs were not established at that time in Europe, in contrast to the USA. During the past 10 years, there has been a clear trend for general practitioners to become increasingly more involved with implant surgery, a trend that is also driven by implant companies. This trend is of concern, especially as undergraduate education of dental students is unable, for various reasons, to provide sufficient clinical training to achieve the necessary skill and experience level for daily practice with implant surgery, as highlighted in a recent review (134). A workshop on dental education clearly suggests that the clinical education and training in implant surgery should be based on postgraduate programs (86). However, there are no hard facts to sustain the suggestion that inexperienced and insufficiently educated or trained colleagues will cause an increasing rate of implant complications or failures. Facts to document this potential fear are absent as this group seldom publishes in scientific journals, as is the case for academic specialists. For instance, excellent 10-year results of numerous clinical studies were obtained by university-based groups with significant clinical experience (4). However, a number of studies support the assumption that an increased failure rate may be expected when surgery is performed by less-experienced surgeons (125, 138, 154). Apart from experience, factors such as skills and judgement also seem to affect the clinical outcome of implant surgery (114). Another observation – that esthetic failures are most often caused by an implant malposition – supports such a theory (60) as these complications are iatrogenic in nature. The future will show if this observation of increased complication and failure rates can be confirmed. Such a trend would have the potential to harm the reputation of implant therapy as a first-choice treatment modality in dental medicine.

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