Contents

1

Introduction, History and General Principles

Douglas Deporter, Domenico Baldi, and Mohammad Ketabi

Background

In the 40 plus years since the first reports appeared from Professor P-I Branemark and his colleagues of the clinical use and success of oral rehabilitation using endosseous, root-form, titanium dental implants [1–3], exhaustive laboratory, animal and human clinical research has led to major advancements in their design and use to replace hopeless or missing teeth. Branemark originally used his implant design, a machine-turned, commercially pure titanium screw, to restore long-standing, fully edentulous patients with splinted fixed prostheses meant primarily to provide occlusal function with no great attention being given to esthetic outcomes. Implants were placed in healed edentulous sites and allowed submerged healing for 6 months or more before being uncovered and restored with suitable prostheses. Survival after 10 years was in the high-90th percentile for mandible, but only in the mid-80th percentile for maxilla, likely due to differences in bone density. Subsequent replication studies in university settings (e.g. Leuven, Belgium; Toronto, Canada) and elsewhere then began to define further the prerequisites, indications and contraindications for their use in partially edentulous cohorts. While no mention of any limitations in implant length or diameter were specified by Branemark, the replication studies [4, 5] reported that Branemark's original design had a high risk of failure (≥ 25%) when used in lengths of less than 10 mm in mandible and less than 13 mm in maxilla, a belief that even today remains in the minds of some clinicians. However, this elevated risk with "short" implants was most likely due to implant design (machined surface topology) and inexperience by the investigators involved, as would later be concluded [6, 7]. The move to implants with moderately rough surface topologies [8] and introduction of titanium alloys containing zirconium to improve material strength [9] was a major advance. Today, we have a wealth of well-designed study results showing that both short (≤8 mm) [6] and even ultra-short (< 6 mm) [10], moderately rough-surfaced threaded implants can offer excellent performance when properly used and restored.

The essential need for submerged initial healing in achieving osseointegration of dental implants also came to be challenged since investigators later learned that non-submerged implant placement in healed edentulous sites worked just fine, provided that initial implant stability was adequate [11]. Indeed, even limited, immediate loading in non-submerged cases started to be reported [12], again if appropriate initial stability could be achieved [13].

The Timing of Implant Placement

The original cohort of patients treated by Branemark had long-standing full edentulism and their implants were inserted into healed edentulous sites, often in primarily basal bone and with mature overlying soft tissues. However, we now know that other approaches can be taken including implant placement (IIP) at the time of tooth extraction ("immediate implantation"; type 1) or in some instances within the following 4–8 weeks ("early implantation"; type 2) after tooth removal, during which time initial soft tissue healing has occurred [14–16]. The advantage here is that an additional 3–5 mm of keratinized mucosa, including a significant mid-facial thickening over thin or damaged facial bone walls, can result [17]. There will also be some new bone formation apically in the socket which may accommodate easier implant bed preparation compared with IIP. Both of these "non-traditional" approaches, while challenging, can be suitable for replacement of non-molar teeth [16, 18–20]. As will be seen, however, immediate placement via flapless surgery and hard tissue gap grafting with immediate provisionalization is the more heavily researched approach [21, 22]. Type 3 implant placement (after 12–16 weeks of healing) can still be indicated in more

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challenging situations, such as when the tooth socket is so damaged that it needs to be reconstructed in advance with guided bone regeneration (GBR), while type 4 coincides with the original Branemark approach of placing implants in long-standing, fully healed edentulous sites.

Current thinking is that "immediacy" (type 1) is often the preferred treatment if the condemned tooth or at least its root(s) remains to be extracted, and if so, two possible approaches have been suggested. In the ideal scenario with all socket walls intact, IIP with gap grafting is the usual choice (Figure 1.1). However, if the tooth has suffered extensive bone loss apically and/or buccally due to an endodontic failure or root fracture, provided that the IIP can be placed within the original boney housing with adequate stability, the principles of GBR can be used to regenerate the lost bone during the period of implant integration (Figure 1.2). Finally, if

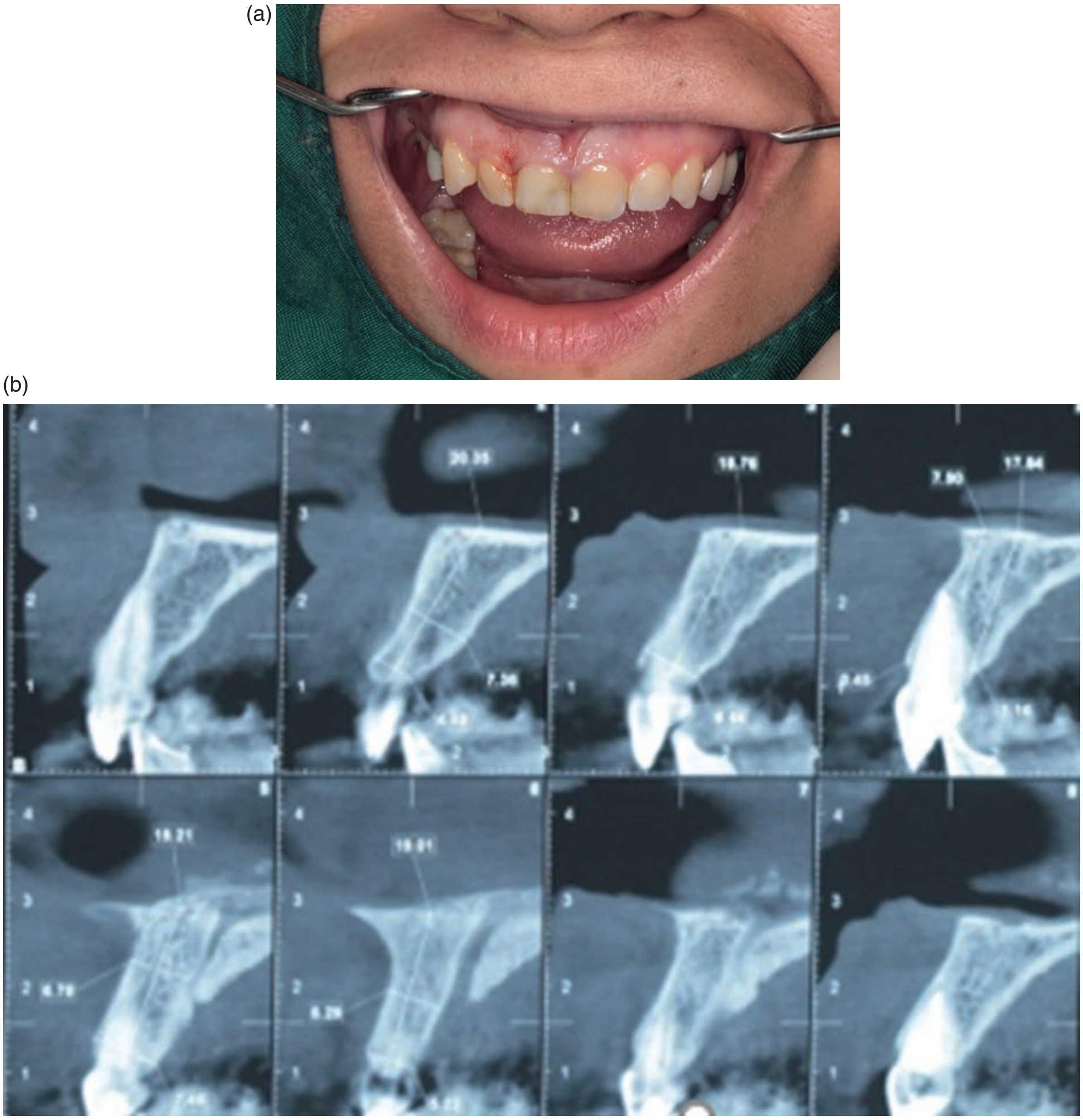


Figure 1.1 (a) This patient presented with a hopeless maxillary right central incisor. (b) Preoperative cone beam computed tomography showed the site to have a very thin buccal plate but adequate apical and palatal bone to place an immediate implant. (c) Flapless extraction was followed by implant insertion in a prosthetically ideal location for a screw-retained restoration. A large buccal gap was intentionally left and packed with particulate bone substitute material. (d) Initially a stock, wide body healing abutment was inserted and the soft tissues sutured. (e) A customized transitional crown was placed. (f) The restored implant after 4 years in function showing stable soft tissue morphology. (g) A radiograph taken at the 4-year recall confirming stable crestal bone levels.

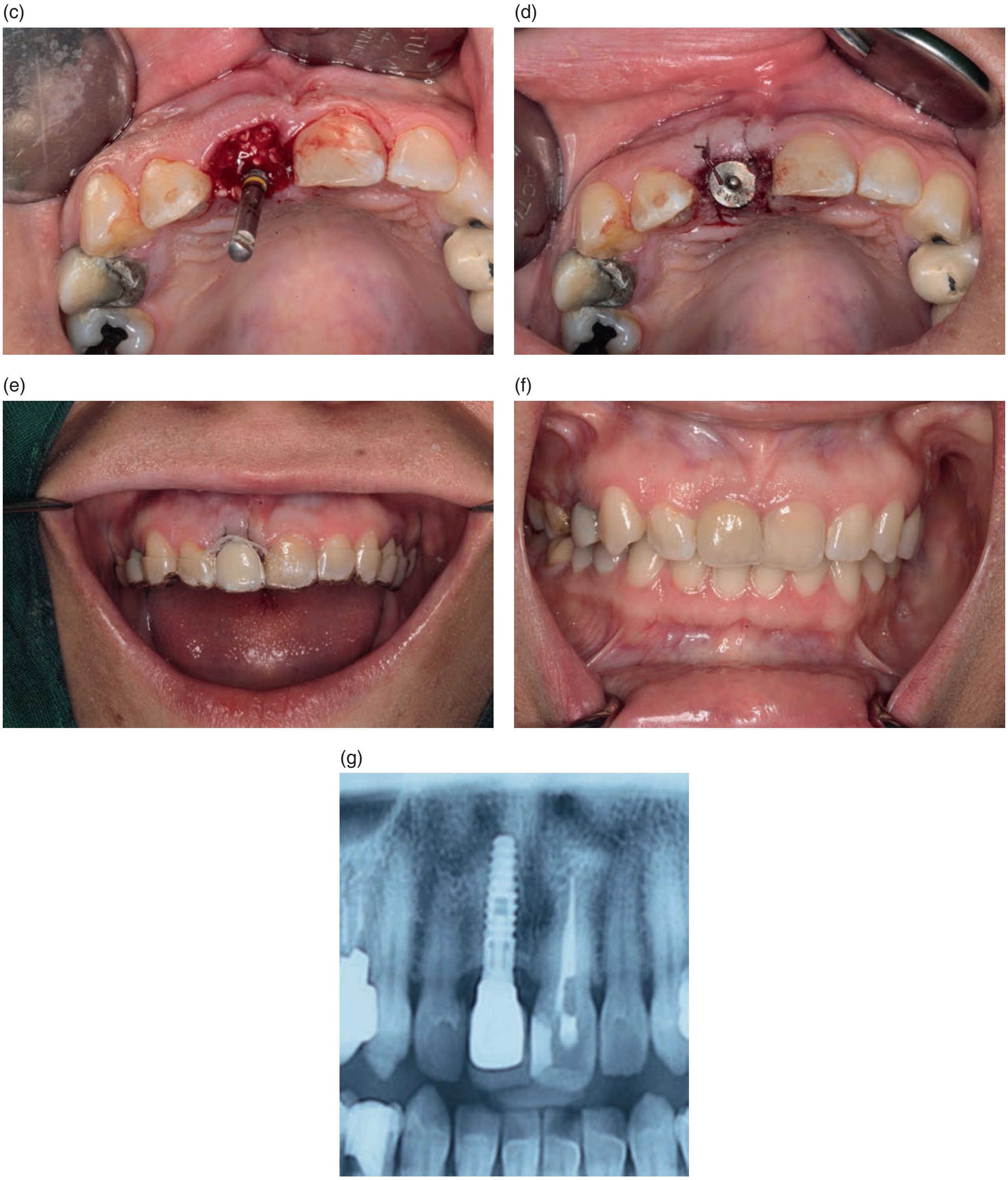


Figure 1.1 (Continued)

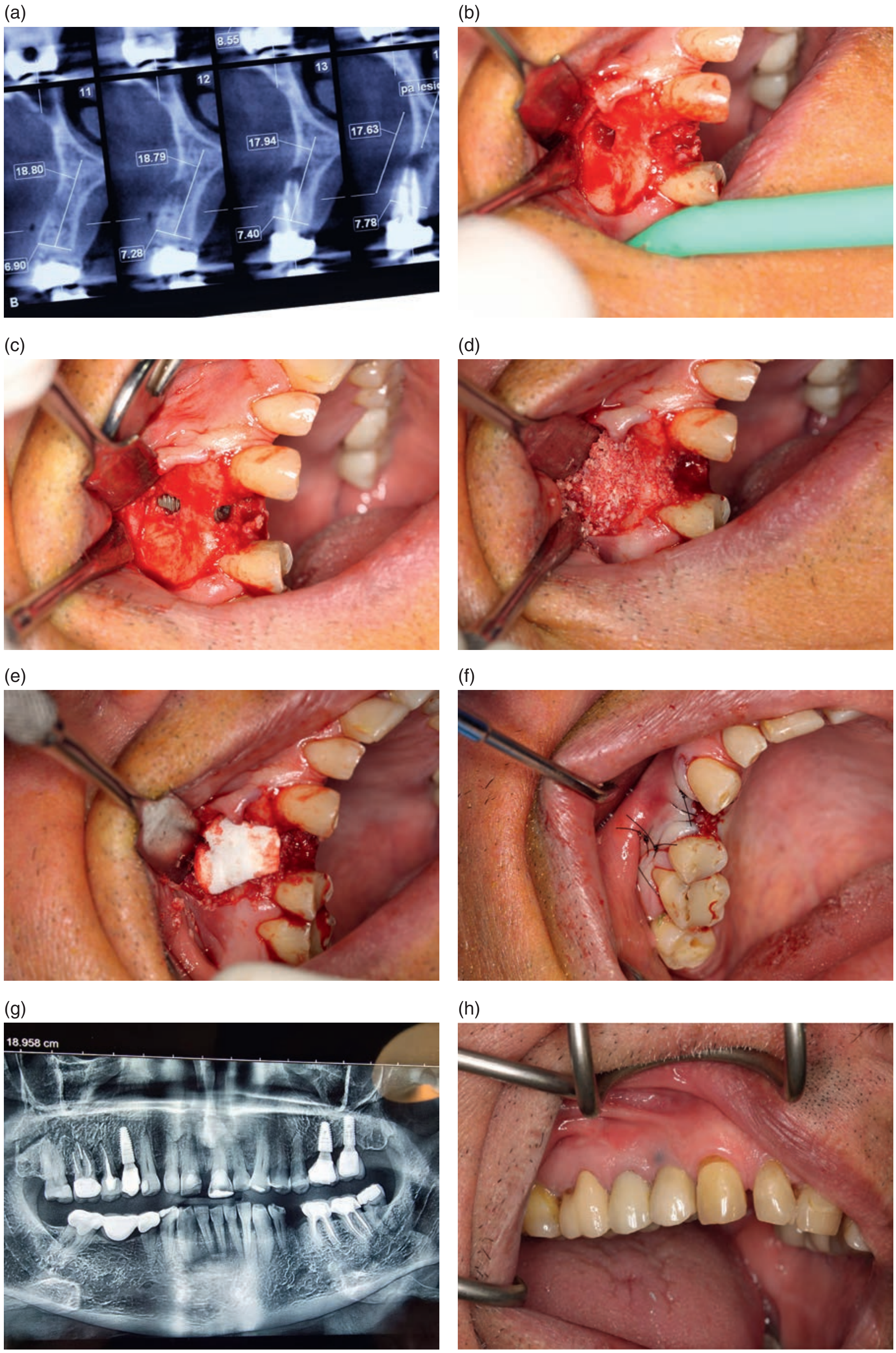


Figure 1.2 (a) This patient presented with a failed endodontic treatment with chronic periapical infection and fenestration of the buccal plate at her maxillary right first premolar. (b) Because of the large buccal fenestration, a mucoperiosteal flap was raised to expose it. (c) After thorough debridement of the socket and periapical lesion, an immediate implant was inserted into the original bony housing. (d) Particulate bone substitute was used to graft the apical defect and buccal plate as well as the peri-implant gaps. (e) A collagen membrane was placed over the graft material. (f) Following periosteal release of the flap it was repositioned and sutured. (g) A panoramic radiograph of restored implant 5 years following surgery. (h) The restored implant 5 years in function.

the damage to the bony walls is so extensive so that it is no longer possible to stabilize an implant within the original alveolar housing, immediacy will not be suitable, with the safer approach being socket preservation grafting [23] and delayed implant placement.

A second case of IIP requiring simultaneous GBR is shown in Figure 1.3a. The patient's maxillary central incisors were extracted revealing major loss of the buccal bone, but it was still possible to secure two implants within the original bony housing of their roots. After ensuring adequate stability of the implants, the large defects were filled with particulate bone allograft, covered with a membrane and allowed 6 months of submerged healing (Figure 1.3b). At that point, cone beam computed tomography (CBCT) revealed significant buccal bone regeneration (Figure 1.3c). To allow wound closure, the large flap had

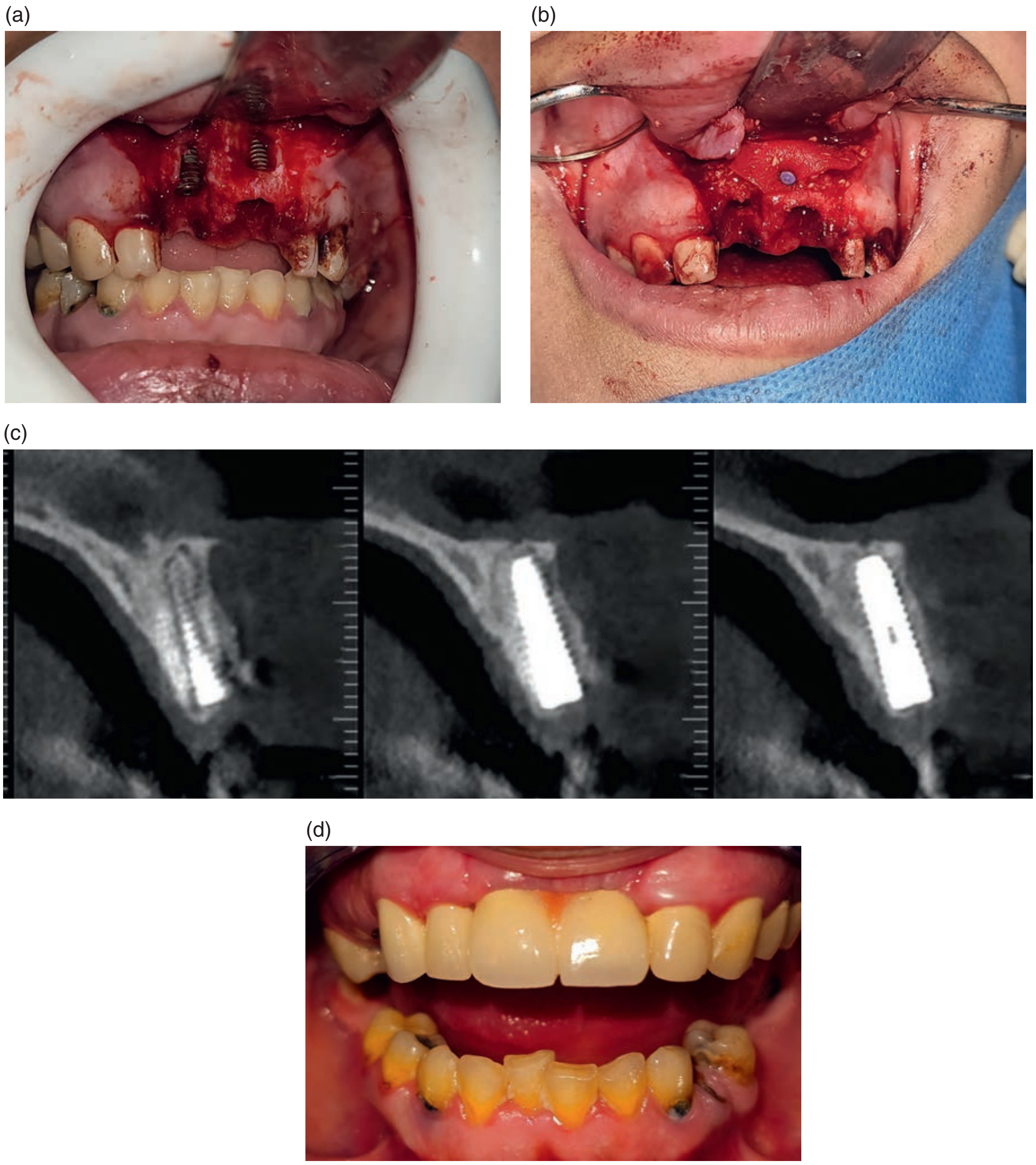


Figure 1.3 (a) Two maxillary central incisors suffered endodontic complications and needed extraction. (b) After implant insertion, the defects were packed with particulate bone allograft material covered with a stabilized collagen membrane. *Source:* Courtesy of Dr. Vahid Esfahanian and Dr. Sorena Abrishamkar, Faculty of Dentistry, Islamic Azad University (Isfahan Branch). (c) Cone beam computed tomography at 6 months of healing revealed regenerated buccal bone and the implants were subsequently restored. (d) The final restoration including pink acrylic to mask the missing midline papilla.

been coronally advanced, which left the buccal covered with alveolar mucosa. Soft tissue grafting was proposed but the patient declined this extra surgery. As a result, it was not possible to regenerate the midline papilla, making it necessary to use a two-unit splinted prosthesis with the interimplant space masked with pink acrylic (Figure 1.3d).

Early Work with Immediate Implant Placement

The earliest report of IIP usage in humans was published in German in 1976 by Schulte and Heimke [24] using ceramic (aluminum oxide, Al_3O_2), press-fit implants, but this implant design was soon overtaken by Branemark's titanium threaded concept. One of the earliest reports using threaded titanium designs for IIP was a case series published by Richard Lazzara [25], the original founder of the 3i Implant Company. He applied the principle of GBR [26] to allow osseointegration of machine-turned threaded implants placed immediately after removing non-molar teeth. After raising a conservative soft tissue flap, minimally traumatic tooth removal and socket debridement, he prepared osteotomies into socket native apical bone to achieve adequate initial implant stabilization, and to a depth so that the implant platform was seated at 2 mm below the crestal bone level. Following implant insertion, the extraction socket opening was draped over and isolated with a Gore-Tex® (WL Gore & Assoc., Flagstaff, AZ) barrier membrane stabilized with sutures. The purpose of the barrier was to prevent connective tissue ingrowth into the socket allowing new bone to form by "distance osteogenesis" [27] arising from the socket walls with eventual implant osseointegration. The Gore-Tex membrane was left exposed, but because of the risk of site infection [28] was removed at 6 weeks. By this time, the peri-implant gaps had filled with new, albeit still remodeling, osseous tissue.

Akimoto et al. [29] subsequently conducted experiments in dogs in which machine-surfaced (i.e. minimally rough [8]) implants were placed in healed mandibular edentulous osteotomy sites intentionally overprepared coronally (by 0.5 mm, 1.0 mm, and 1.4 mm) relative to the diameter of implants being used, but of appropriate diameter apically to achieve implant stability. None of the coronal peri-implant gaps were grafted with bone substitute, nor were any barrier materials used to cover the implanted sites prior to soft tissue flap closure to allow undisturbed submerged healing. After 12 weeks of healing and animal euthanasia, the retrieved jaw segments were defleshed to reveal macroscopically that all gaps appeared to have healed with complete bone fill. However, subsequent histological assessment revealed that fibrous connective tissue had developed between newly formed bone and implant surface to variable depths such that the wider the initial gap, the more fibrous tissue found. Clearly, healing by "distance osteogenesis" [27] alone with no barrier protection had been too slow to avoid the invasion of fibroblasts, and the authors suggested that moderately rough-surfaced implants [8] might have performed better by promoting "contact osteogenesis" [27]. Botticelli et al. [30] later confirmed this suggestion with a dog study using moderately rough [8], SLA (sand-blasted large grit acid-etched)-treated (Straumann AG, Waldenburg, Switzerland) implants (length 10 mm; width 3.3 mm). Peri-implant gaps of 1.25 mm width were created around the coronal-most 5 mm of implant length. The gaps on one side of each mandible were filled with deproteinized cancellous bone mineral (Bio-Oss®, Geistlich Sons Ltd., Manchester, UK) while those on the contralateral side were left ungrafted. Finally, all sites were covered with resorbable barrier membranes and allowed submerged healing. Four months later, histological assessment of retrieved specimens showed all gaps, grafted or not, to be filled with bone confirming the importance of guided healing using membranes, at least when implants were submerged using primary wound closure. Later, following work by others, the consensus became that moderately rough IIPs with peri-implant gap distances greater than 1.5–2 mm most likely required placement of allograft or xenograft bone particles covered by some sort of membrane to allow complete submerged bone healing up to the implant surface [31, 32].

Later still, clinical opinions on the need for gap grafting changed once more, with influential clinicians claiming that, provided that flapless surgery and non-submerged healing were employed for tooth extraction/IIP, any size gaps would fill with bone spontaneously as long as the blood clots occupying them were not disrupted during initial healing [33–35]. However, if grafted gaps left were small ($\leq$ 2 mm), post-extraction alveolar ridge shrinkage was seen to endanger sites with initially thin buccal bone [36]. So yes, peri-implant gaps adjacent to moderately rough-surfaced implants, regardless of their size, will fill with bone naturally, but gap grafting is still indicated to minimize buccolingual alveolar ridge shrinkage with IIPs [37], and especially in anterior maxilla, where buccal bone is commonly very thin. Failure to include gap grafting also has been linked to immediate implant failures. For example, Covani et al. [38] found that IIP survival at single-rooted tooth sites after 10 years in function was 87.9% at non-grafted compared with 94.1% at grafted sites.

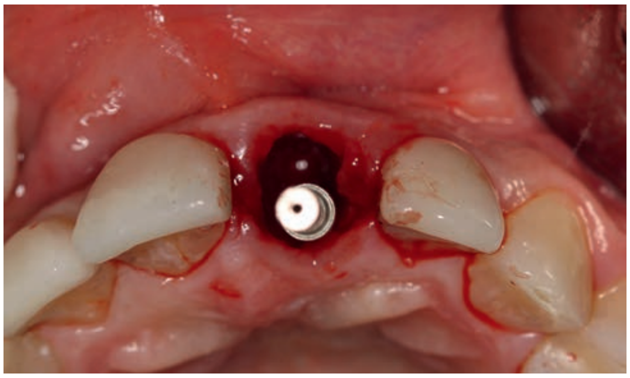
Currently, as demonstrated in this book, the consensus with IIPs at sites with intact socket walls is to use flapless surgery, minimally traumatic tooth extraction, gap grafting with a particulate bone substitute and non-submerged initial healing following placement of a wide-diameter stock or customized healing abutment or temporary restoration to: (i) protect the added graft material; (ii) support the original socket soft tissue margins; and (iii) provide some degree of non-occlusal loading to the implant to kickstart osteogenesis [39]. However, using IIPs is recognized by experts as being technically challenging [40], particularly for surgeons with limited experience, because of high risks of disastrous esthetic complications, especially in anterior maxilla [41, 42]. To provide successful IIP treatment in the esthetic zone, the clinician needs to have the essential skills of delicate soft tissue manipulation using flapless surgery, minimally traumatic extraction methods, familiarity with bone of different qualities and appropriate ways to compensate for them if need be, selection of appropriate implant designs, three-dimensional (3D) prosthetically ideal implant positioning, well-controlled site drilling, proper assessment of initial implant stability, and, of course, most importantly recognizing when IIP is inappropriate. In the end, success with "immediacy" at non-molar sites for both clinicians and patients is now defined as a stable esthetically pleasing outcome replicating natural teeth. If this cannot be anticipated, IIP may not be the treatment of choice [43].

Biological Benefits of "Immediacy"

There are significant biologic advantages with IIPs since as already mentioned, with gap grafting they help to minimize the alveolar ridge bone shrinkage routinely seen following tooth extraction and unassisted healing [44–46]. Following tooth removal, periodontal ligament and "bundle bone" [47] are quickly lost due to the reduced functional forces received by the remaining alveolar bone. This leads to a dramatic buccolingual/palatal ridge shrinkage of up to 50% in the first 3 months or so [48]. The impact is particularly dramatic at maxillary anterior tooth sites where facial/buccal bone wall thickness is typically less than 1 mm and therefore can completely disappear within 6–8 weeks post-extraction. Chappuis et al. [49, 50] reported that the average mid-buccal loss in width at these sites was 7.5 mm. This drastic loss in healing ridge width can be significantly reduced by "socket preservation grafting" [51] at the time of tooth removal, but this adds expense and time to the implant treatment since a second series of appointments then become necessary for delayed implant insertion. It is, however, becoming increasingly apparent that IIP placement with grafting of peri-implant buccal gaps using particulate bone allograft or xenograft can be an effective way to reduce this ridge shrinkage [52, 53]. Most clinicians elect to place the graft material after securing the implant, but an alternate approach can be to place the graft material before inserting the implant to ensure that it is well compacted [54]. This latter approach, however, requires redrilling of the osteotomy with the same bur used for the initial osteotomy, with the surgical guide in place, at a very slow speed and without saline, to keep the graft particles in place [54].

The larger the gap being grafted the better (Figure 1.4a, b). For example, Levine et al. [36] recently published CBCT findings up to 5 years after IIP treatment in anterior maxilla comparing buccal gaps of 2 mm or less with gaps greater than 2 mm. All were grafted with particulate xenograft, but where gaps of less than 2 mm had been left, there was significantly more buccal thinning and vertical bone loss, the ultimate result being significant loss of bony covering on buccal

(a)



(b)

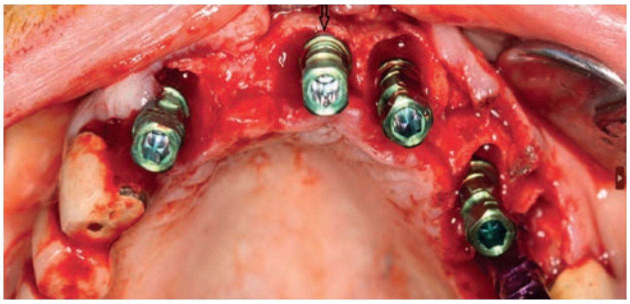


Figure 1.4 (a) A large (> 2 mm) buccal gap between implant and buccal bone wall needs to be left for grafting with slowly resorbing particulate bone substitute. (b) The gap left at the implant marked with the arrow was too small for effective grafting making buccal onlay grafting essential to avoid loss of buccal plate.

implant surfaces. While this may not result in complete denudation of bone from the buccal implant surface, it most likely will lead to some loss in crestal bone height and associated gingival recession. Buccal bone thickness needs to be at least 1.8 mm to accommodate the vasculature necessary for nutrients supporting appropriate remodeling and long-term bone maintenance [55]. To reduce this risk with narrower gaps, it is prudent also to include contour grafting buccally under the periosteum [56]. Capelli et al. [57] went further, suggesting that if the distance from the implant surface to the outer aspect of the buccal plate is less than 4 mm, this "external grafting" should always be included. Xenograft particles covered with a resorbable membrane were used by Capelli for both gaps and for external grafting, although others believe that the barrier in unnecessary and that the particulate xenograft can simply be inserted in a surgically created buccal pouch [58, 59]. Others have proposed using autogenous connective tissue grafts to increase buccal soft tissue thickness to minimize soft tissue recession [60].

Box 1.1 Checklist of Diagnostic Parameters for Immediate Implant Placements

- Tooth type
- Buccal bone thickness (cone beam computed tomography)
- Bone sounding of adjacent teeth + periapical radiographs
- Gingival level relative to adjacent teeth and contralateral counterpart
- Gingival phenotype (thick or thin)
- Width of keratinized tissue
- Osseous crest to gingival level of hopeless tooth
- Sagittal root position (cone beam computed tomography)
- Buccopalatal ridge width
- Mesiodistal ridge width
- Virtual simulated implant placement
- Virtual or laboratory diagnostic wax-up

Source: Modified from Kan et al. [63].

Indications for Immediate Implant Placement in Anterior and Premolar Sites

Proper case selection is crucial in proposing IIP treatment, including reasons for tooth extraction, which may be non-restorable caries, root fractures, root resorption, questionable teeth in need of endodontic retreatment, teeth fractured at the gingival margin with unfavorably short roots, and especially when questionable teeth may be being considered as abutments for traditional fixed partial dentures. Placement of immediate implants has its longest history in maxillary anterior and premolar sites (i.e.: the "esthetic zone") and documented findings have allowed considerable refinement of treatment approaches.

Maxillary incisor sites may seem to the uninitiated as the ideal sites for IIPs because of easy access, single-rootedness, and patients' urgent needs of replacement for esthetic reasons. Indeed, the authors of one recent systematic literature review with meta-analysis of immediate implant performance at different tooth locations suggested IIP to be the preferred approach for maxillary anteriors [61]. However, for many reasons, these sites may be the most difficult to obtain optimal or even acceptable long-term outcomes [62]. The scallop of the periodontium, level of crestal and interproximal bone, expected tooth-to-implant interproximal distance, morphology of the gingival tissues, smile line and patient's esthetic expectations must be considered before initiating treatment. Box 1.1 [63] shows a suggested list of essential diagnostic parameters needed for favorable treatment outcomes. The ideal scenario for IIP in the esthetic zone will be a healthy individual who is a non-smoker, with a low lip line, a thick, low-scalloped gingival phenotype, rectangular tooth shape, no infection, ≤ 5 mm distance from the future contact point with the adjacent teeth to the bone crest [64], adequate mesiodistal ridge width (≥ 7 mm), minimal buccal bone anatomical undercuts and an intact facial bone plate ≥ 1 mm in thickness at the crest [63, 65] (Figure 1.5a). Triangular tooth shapes may be a serious limitation, as they often display thin, highly scalloped gingival margins, and particularly if there is a reduced height of interproximal bone affecting the adjacent teeth. Unless the tooth shape here can be altered, significant "black triangles" can be anticipated with the final restoration.

It has been recommended that the gingival level of the failing tooth should be at the same level as (or more coronal to; Figure 1.5b) that of the contralateral tooth and harmonious with the adjacent teeth [63]. When the gingival level of the failing tooth is more apical than that of the contralateral tooth, orthodontic forced eruption should be considered before deciding on implant placement immediately post-extraction [66].

As already stressed, the facial/buccal bone plates of maxillary anterior teeth, including canines, are generally very thin [67], so thin in fact that their thicknesses cannot always be accurately determined with CBCT with dehiscences often erroneously predicted when not present (Figure 1.6) [68]. The great majority have facial bone thicknesses at the alveolar crest of ≤ 1 mm [67, 69]; that is, primarily the thicknesses of bundle bone and a thin bit of cortex. As such, they are at great risk for significant crestal

(a) (b)

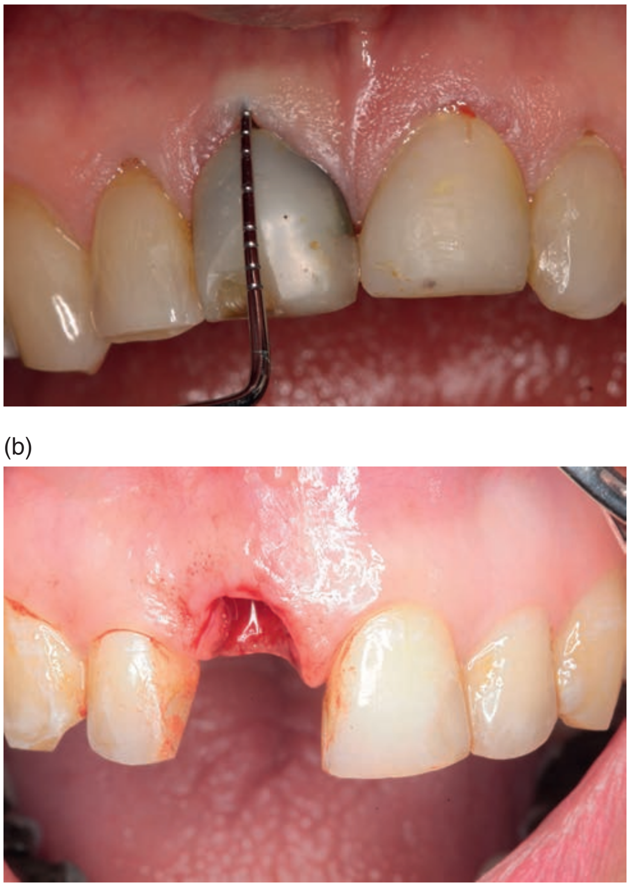


Figure 1.5 (a) This right central incisor would be a good candidate for immediate implant placement (IIP) with its square tooth shape, favorable interdental papillae, minimal bone crest to gingival margin distance, gingival outline similar to the left incisor, thick gingival phenotype and wide band of keratinized tissue. Consideration should be given to the need for frenectomy. (b) A favorable site for an IIP, although consideration should be given to adding a small connective tissue graft to minimize the risk of gingival recession relative to the contralateral tooth.

bone loss following tooth extraction [49, 70], as well as for greater buccolingual alveolar ridge shrinkage [71, 72]. While very thin facial bone can withstand normal biomechanical forces generated by the original teeth, following extraction, loss of periodontal attachment and implant placement, the same biomechanical forces are much more likely to cause facial bone resorption [73]. These findings explain why the anterior maxilla presents such a high risk of peri-implantitis development [74].

Tsigarida et al. [67] undertook a systematic literature review and meta-analysis of buccal/facial alveolar bone (FAB) thicknesses at three levels (crestal, mid-root, and apical) of maxillary incisors, canines, and first premolars calculating mean FAB thickness values. None of the thickness values calculated were ≥ 1.5 mm, a critical threshold for FAB

Figure 1.6 A typical very thin buccal plate over a maxillary incisor.

below which significant thinning and vertical resorption are almost certain to occur after tooth extraction [75, 76]. Therefore, flapless surgery to avoid interruption of the vital blood supply to buccal bone and careful tooth removal are essential if there is any hope of preserving this bone [77, 78]. Prior to undertaking IIP treatment in the esthetic zone, a diagnostic wax-up of the ideal final restoration is best undertaken, ensuring that it will complement the contiguous teeth and contralateral partner [63]. Some clinicians also suggest that a temporary crown for the tooth being removed should be created before extraction, to have it available to use as an immediate transitional restoration for the implant [79].

Less attention has been paid to the importance of palatal bone thickness (PBT) at maxillary anterior root sockets. One recent study reported CBCT data of palatal wall thicknesses at these sites, and again the majority were recorded as being less than 1 mm crestally [80]. However, significantly less loss in PBT compared with FAB contributes to post-extraction horizontal alveolar ridge shrinkage, suggesting that PBT may be less of a concern with IIPs at these sites. This may relate to thick palatal soft tissue, avoidance of flap elevation and proximity to the considerable local blood supply arising from the nasopalatine vessels [80].

Extractions for immediate implants should be as minimally traumatic as feasible. Nevertheless, they do lead to an amplified inflammatory process initiating a cascade of events in the residual socket bone, leading to both vertical and horizontal bone resorption [81], especially on the buccal aspect [82] (estimated in dogs to be approximately 45 microns per day [83]). This loss is further amplified if soft tissue flaps are raised [84].

Clinicians have continuously sought new approaches for extraction respecting the concept of "minimally invasive surgery." Scientific research has resulted in the development of instruments including fine periotomes to sever proximal transseptal fibers of the periodontium, piezoelectrical surgical devices, Physics Forceps and magnetodynamic instruments.

Use of piezoelectric devices is now widespread in various oral surgical procedures including tooth extraction [85–89]. They convert electrical impulses into mechanical vibrations via modulated ultrasound frequencies of 24–29 kHz and microvibrations of 60–200 μ amplitude. This provides several advantages, including: (i) cutting precision; (ii) prevention of possible complications such as alveolar/radicular fractures; (iii) high level of safety in proximity to vital structures and soft tissues; (iv) reduction of bleeding; (v) some disinfection; (vi) less postoperative discomfort; and (vii) faster healing [90–95].

Physics Forceps are manual forceps that have been designed to reduce the need for excessive force leading to root fractures. Equipped with "protective valves" on their vestibular side and a thin valve lingually, they provide a first-degree lever, applying constant pressure to gradually lift the root. A 2022 systematic review assessed 11 studies using these instruments and concluded that they do offer a reliable, less invasive approach, and shorter intraoperative times than conventional forceps [96].

The original magnetodynamic hammer was developed in 1873 for use in compacting gold material during tooth restoration, but more recently, magnetodynamics have been introduced into the field of oral surgery. The "Magnetic Mallet" (Meta Ergonomica Srl, Turbigo, Italy) uses controlled forces with minimal impact time but maximal force. The device (Figure 1.7) has a power supply that allows its handpiece to be adjusted to four different preset force intensities, and different inserts can be used depending on the intervention being performed and bone density.

The Magnetic Mallet's operation is based on Faraday's law of electromagnetic induction, which states that changing magnetic field forces induces electrical currents in a conductive material. In this case, a copper coil is subjected to a changing magnetic field generated by an electromagnet. When the magnetic field changes rapidly, electrical currents are induced in the coil, generating a repulsive force between tip and handpiece. This results in short-time, rapid, controlled, constant, and repeatable insert acceleration with significant propulsion/penetration forces and limited dispersion into surrounding tissues [97]. Local plastic deformation of bone allows total absorption of the energy created.

Figure 1.7 A Magnetic Mallet with handpiece inserted.

Magnetodynamic inserts (Figure 1.8) are used in sequence first (Extr1F) to create a space between the root and alveolar bone, allowing insertion of subsequent inserts. Space is created in the long axis of the periodontium on mesial, distal, and then lingual/palatal aspects. For most single-rooted teeth, once space has been created, the Extr2F insert is used to extrude the tooth. Molar extraction involves a priori separation of the roots followed by the sequential use of inserts Extr1F, Extr2F, Extr3F, and rarely Extr4F, and Extr5F. The goal is to dislocate the tooth with minimal disturbance to surrounding alveolar bone. After inserting each insert, it can be angled at 30–45 degrees with respect to the root axis. The procedure should begin with the level 1 power setting, and if necessary, increasing to level 2. Starting with power level 3 or 4 may result in loss of control of the handpiece applying sufficient force to cause fracture of surrounding bone trabeculae [98, 99]. In most cases, once visible dislocation is achieved, the tooth can be removed with traditional forceps grasping it below the cemento-enamel junction and using rotary movements.

Figure 1.9 shows atraumatic extraction of a mandibular left bicuspid using a magnetic mallet. Following successful tooth removal from anterior maxilla, the implant osteotomy generally needs to be initiated close to or often into the palatal bone wall in order later to leave a buccal gap of 2 mm or greater between the future implant buccal surface and delicate buccal/facial plate. [36] This was elegantly demonstrated in a publication by Gluckman et al. [100], in which they proposed a classification of maxillary anterior teeth based on their sagittal root positions as depicted in CBCT (Table 1.1 and Figure 1.10). Their class I-A (root located centrally with a buccal plate > 2 mm) is clearly the best site for a maxillary incisor IIP. However, only about 5% of maxillary incisor and 8% of maxillary canine tooth roots were given this classification. The great majority of radial/sagittal tooth positions were classified as class II (root apices inclined facially with either a thick or thin cortical bone plate). Class III sites (9.5%) had coronal segments inclined facially; class IV (7.3%) were positioned beyond the alveolar bone envelop facially; and finally, class V (0.7%) had both very

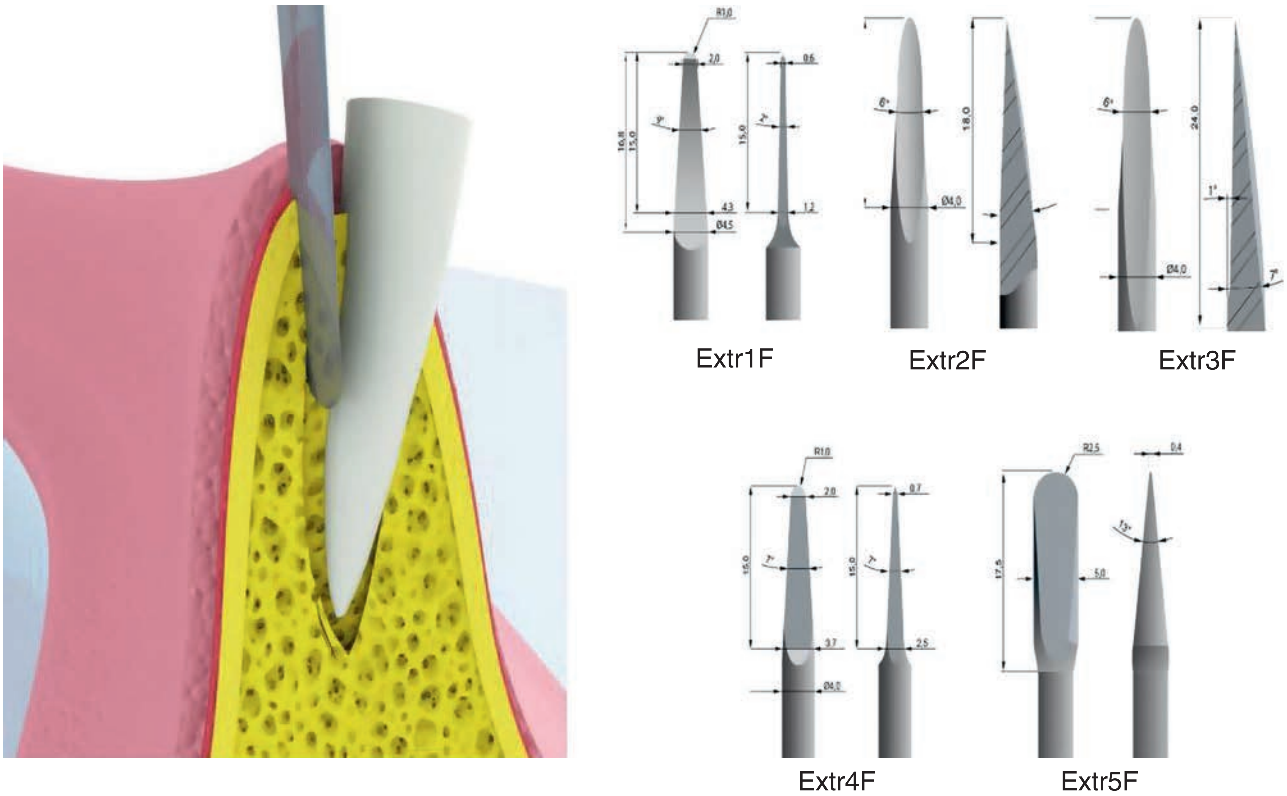


Figure 1.8 A set of Magnetic Mallet extraction tips.

thin buccal and palatal bone plates. As part of the same publication, the authors used this classification system to determine the preferred location of the initial osteotomyentry point for each class in order to leave sufficiently wide buccal gaps for grafting (Figure 1.11). For class I sites, it was recommended that the initial osteotomy entry point be located at the root apex either following the radial/sagittal root direction for cement-retained restorations or hugging the socket palatal wall for the preferred screw-retained prosthesis. The initial osteotomy entry points for class II and III sites were recommended to be located in the palatal wall approximately one-third from the socket apex. For class IV situations, this entry point should be located about half the palatal bone wall length from the socket apex.

Wychowanski et al. [101] conducted a retrospective radiologic study of preoperative (before extraction) and post-implantation CBCT records from 300 patients who each had received IIPs in the anterior maxilla. They found that careful control of the initial osteotomy entry point had allowed successful IIP in 78.3% of the sites. The procedures were relatively straightforward in those cases where the initial entry point was possible through the socket apex (22.8%) but more challenging where the entry point needed to be at some level of the palatal socket wall (56.3%).

The choice of implant diameter also is fundamental in establishing wide gaps buccally between the implant once inserted and the buccal bone plate. Mean facial–palatal socket widths of maxillary central and lateral incisors are documented as 6.34 ± 0.48 mm and 5.76 ± 0.44 mm (Table 1.2) [102], respectively, making it challenging to leave the requisite minimal 2 mm facial gap with placement of standard diameter implants. Caneva et al. [103] demonstrated data relevant here in a canine investigation. They studied the influence of implant diameters on the healing of peri-implant bone with IIPs in dog premolar sites comparing diameters of 3.3 mm and 5 mm. The narrower diameter implants were positioned centrally in the recipient root sockets, and while small gaps remained around the implants, they were not grafted. In contrast, the wider diameter implants filled their entire root sockets making direct contact with the bony walls. The result, of course, was retention of buccal bone with the 3.3 mm diameter implants but substantial loss of buccal bone with the 5 mm diameter implants.

Rosa et al. [104] recommended that at least for maxillary anterior IIPs, the buccopalatal socket widths should first be assessed from cross-sectional CBCT images. In their study of 20 patients each seeking IIP of a maxillary

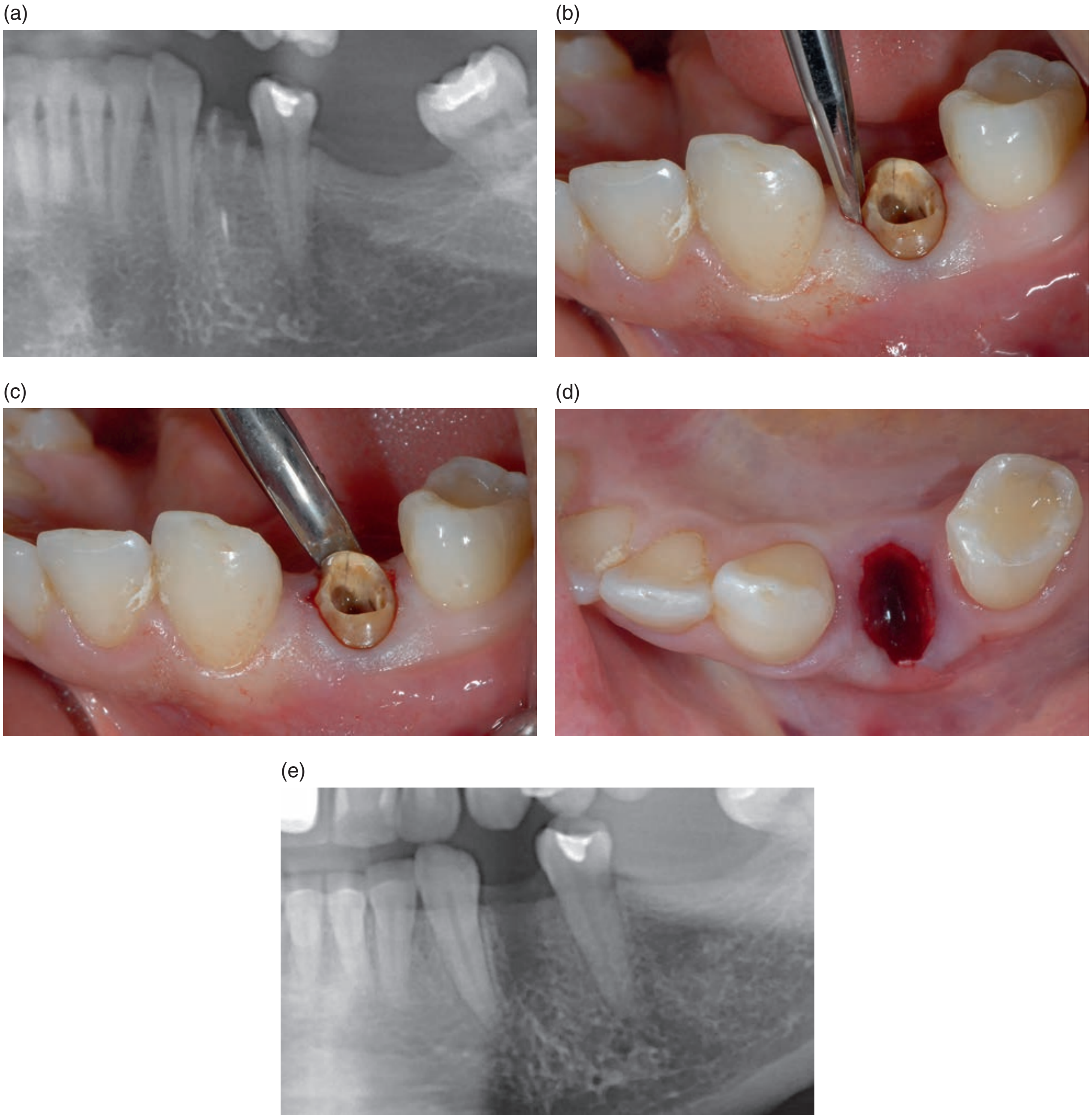


Figure 1.9 (a) This mandibular carious and fractured first bicuspid retained root that had been previously endodontically treated required extraction. (b) The Extr1F and Extr2F inserts were used mesially and distally to initiate loosening of the root fragment using a flapless approach. (c) To complete the luxation, the tips were used lingually but not buccally. (d) The loosened root was removed with minimal trauma using Physics Forceps. (e) The extraction led to no damage to the socket integrity.

anterior tooth (85% centrals, 10% laterals and one canine), the mean buccopalatal socket width at the crest was 7.07 ± 0.37 mm. Implant diameters were chosen with the intention of leaving buccal gaps of 3 mm to be grafted with autogenous bone from the tuberosity (see also Chapter 6).

Proper insertion depth of the implant also is important to minimize the impact of any anticipated vertical crestal bone loss. Ideally, the implant will be subcrestal to the level where the buccal bone thickness is at least 1.5 mm [75]. Implants with internal conical prosthetic connections should be inserted approximately 2 mm subcrestal buccally to avoid later esthetic complications due to loss of crestal buccal bone and subsequent gingival recession [105, 106]. Subcrestal placement will also help to increase gingival thickness over the implant, again helping to minimize crestal bone loss [107, 108].

Table 1.1 Classification of radial root positions for maxillary incisors.

Class	Descriptor: Vertical axial inclination, buccopalatal orientation of tooth in ridge, thickness of bone wall(s)
I	Tooth centrally positioned within ridge
IA	Thick facial bone wall (≥ 1 mm)
IB	Thin facial bone wall (< 1 mm)
II	Tooth retroclined
IIA	Thick crestal bone
IIB	Thin crestal bone
III	Tooth proclined: typically, thick palatal bone, thin facial crest, thick facial wall apically
IV	Tooth facially positioned outside of bone envelope
V	Thin facial and palatal bone walls

Source: Gluckman et al. [100].

Similar considerations need to be addressed with IIPs at cuspid and premolar sites. Mean buccolingual widths of maxillary canine root sockets have been reported as 7.5 ± 0.62 mm, while mean buccolingual widths of maxillary first and second premolars are 8.99 ± 0.60 mm and 8.45 ± 0.56 mm, respectively (Table 1.2) [102].

Mesiodistal positioning of an IIP, especially at lateral incisor sites clearly must be considered an esthetic risk. Mean mesiodistal socket width with maxillary lateral incisors is only 4.38 ± 0.53 mm (Table 1.2), making the choice of an appropriate implant diameter once more a key issue. If as often happens, a lateral incisor implant is planned between its adjacent central incisor and canine, insufficient space left interproximally (< 1.5 mm) may lead to bone loss at the tooth surfaces leaving insufficient bony support and vascularity to permit adequate papilla reformation [62, 109]. "Mini implants" (diameters < 3 mm) might be an option, but they do show survival rates lower than implants of diameter > 3 mm [110]. In any event, at maxillary lateral incisor sites,

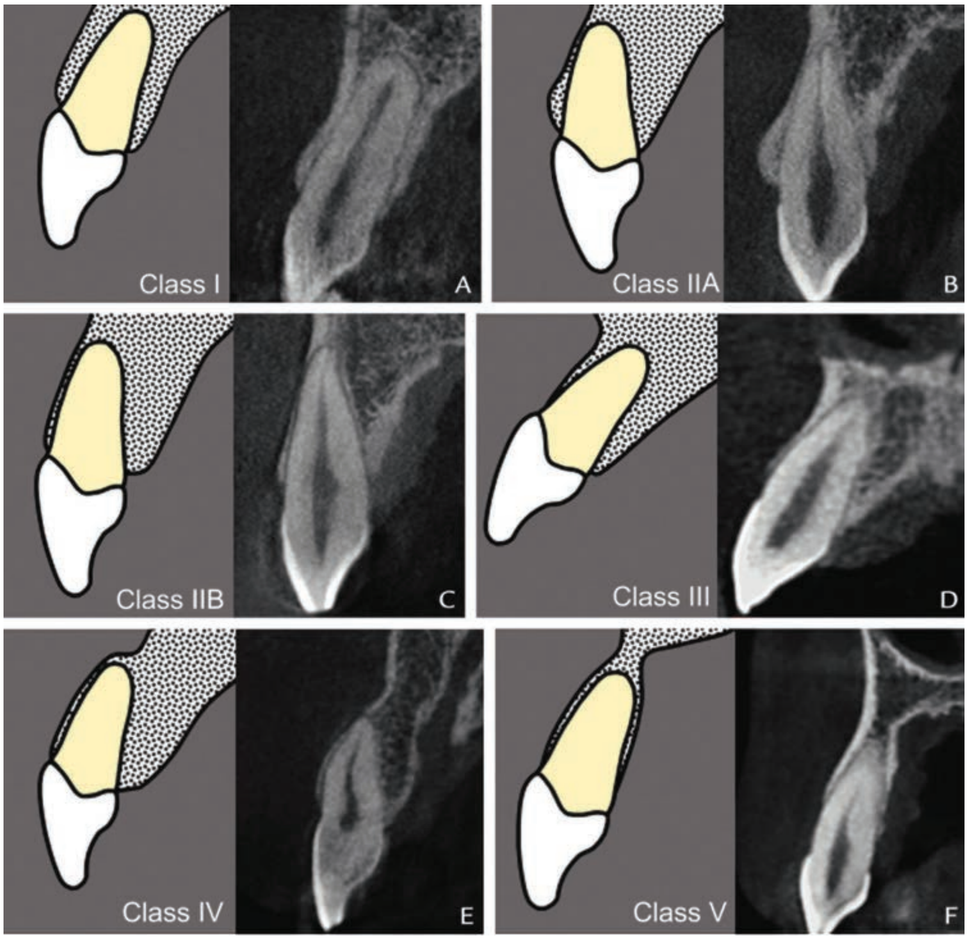


Figure 1.10 Radial root positions in sagittal cone beam computed tomography images classified by Gluckman et al. *Source:* Gluckman et al. [100]/Elsevier.

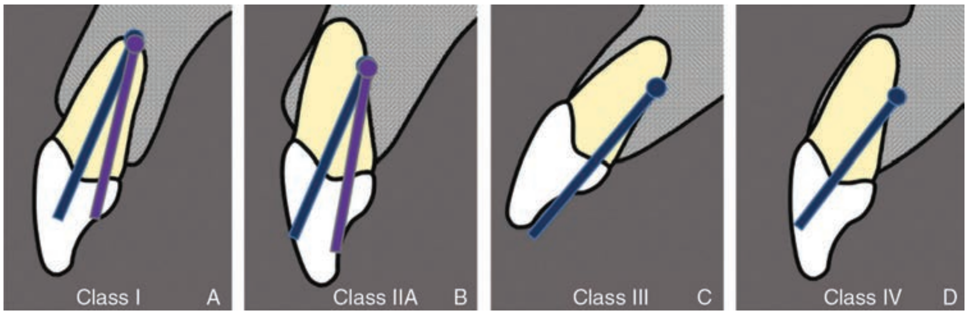


Figure 1.11 Suggested osteotomy initiation points for maxillary anteriors [100].

Table 1.2 Mean values of socket orifice dimensions by tooth type.

	Linear measurements						
	Central incisor (mm)	Lateral incisor (mm)	Canine (mm)	First premolar (mm)	Second premolar (mm)	First molar (mm)	Second molar (mm)
BL maxilla	6.34 ± 0.48	5.76 ± 0.44	7.50 ± 0.62	8.99 ± 0.60	8.45 ± 0.56	11.08 ± 0.60	11.08 ± 0.59
BL mandible	5.87 ± 0.26	6.02 ± 0.43	7.43 ± 0.72	7.08 ± 0.55	7.34 ± 0.67	9.38 ± 0.76	9.15 ± 0.61
MD maxilla	6.21 ± 0.58	4.38 ± 0.53	5.13 ± 0.46	4.75 ± 0.66	4.81 ± 0.43	8.13 ± 0.71	7.82 ± 0.56
MD mandible	3.52 ± 0.24	3.59 ± 0.45	4.96 ± 0.56	4.955 ± 0.41	5.03 ± 0.46	9.73 ± 0.84	9.39 ± 0.69

BL, buccolingual; MD, mesiodistal.
Values are shown as in mean ± SD, all from a sample of 30 teeth.
Source: Reprinted with permission from Couso-Queruiga et al. [102].

ensuring that a narrow diameter implant has a built-in platform switch feature will be helpful by allowing interproximal space of 1 mm is to be used [111, 112].

When IIPs are planned for premolar sites (see Chapter 4), implant positioning towards the lingual/palatal and slightly (at least 1 mm) subcrestal relative to the buccal bone crest also will be needed to ensure that appropriately sized buccal gaps suitable for hard tissue grafting remain. FAB thickness does increase from anterior to posterior tooth sites [113, 114] with, for example, 27.5% of maxillary first premolar sites having FAB thickness greater than 1 mm [115]. Nevertheless, placing implants too close to the buccal plate (i.e. ≤ 2 mm) and at the level of the bone crest will almost certainly lead to sufficient vertical bone loss to result in gingival recession and possible exposure of the margins of implant restorations, and even implants themselves [76, 116]. A slight buccal inclination of premolar implants in maxilla may help to avoid fenestrations buccally related to local anatomy [117].

Impact of Socket Configuration on Immediate Implant Placements

A number of socket classification systems have been published to help in determining whether IIPs are appropriate for maxillary incisors. Elian et al. [118] proposed a three-tier system that considered both existing soft and hard tissues (Figure 1.12a–d). Type I sockets were designated the easiest and most predictable, as they had intact buccal bone, a thick gingival phenotype, and no gingival recession. At the opposite extreme, type III sockets were the least appropriate, if at all, for IIPs, as they had no buccal bone and considerable soft tissue recession. In between these types was type II, characterized as having some buccal bone loss but no significant gingival recession. Certainly, before the widespread use of diagnostic CBCTs, the authors noted type II sockets as being deceptive and with the highest rate of poor outcomes with IIPs. A sub-classification for this system (Figure 1.13) was introduced in 2015 to provide more details for type 2. Type 2A sockets were labeled as those with a dehiscence defect affecting only the coronal one-third of the buccal bone plate (up to 6 mm from the gingival margin), while type 2B were those with dehiscences up to 9 mm from this margin. Finally, type 2C were identified as those sockets with dehiscences of ≥ 10 mm from the gingival margin (i.e. extending into the apical one-third of the tooth root).

The most recent and comprehensive classification of single-rooted extraction sockets was recently published by Sabri et al. [120], following a review of previous systems. This new approach takes into consideration a combination of patient-related factors, as well as the usual clinical and radiographic parameters. Class I sockets again are seen as

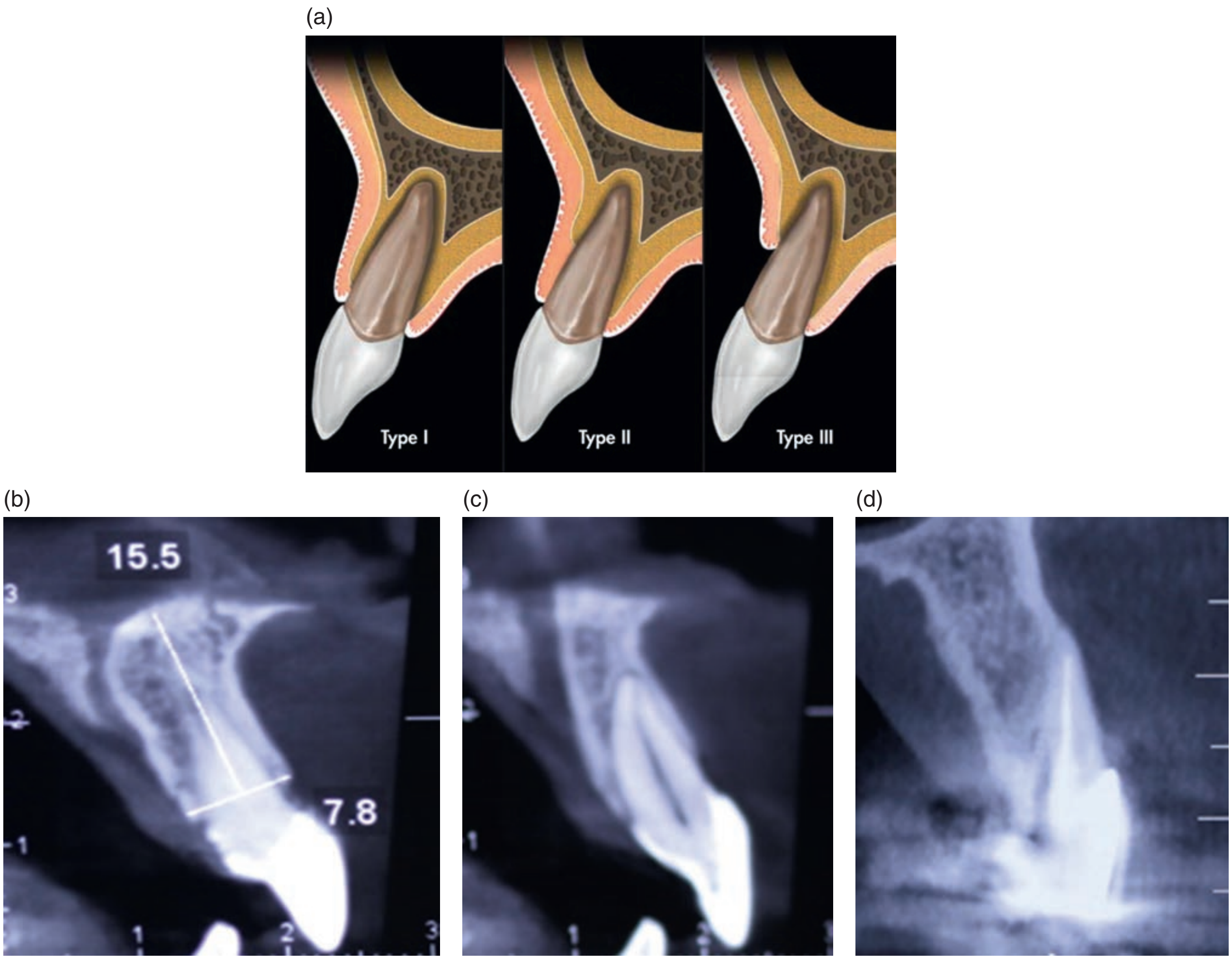


Figure 1.12 (a) Three socket types based on the amount of buccal bone and degree of gingival recession [118]. (b) An example of an Elian type I socket favorable for immediate implant placement. (c) An example of an Elian type II socket. (d) An example of an Elian type III socket.

those with ideal conditions to receive IIPs. The reason for tooth extraction from these sockets should be primarily related to endodontic issues, advanced caries or root fracture. Gingival recession affecting the condemned tooth must be ≤ 3 mm with a thick phenotype and CBCT assessments should show favorable sagittal root positioning, buccal bone thickness of at least 2 mm and without signs of obvious dehiscence, interproximal bone loss, or apical pathology. Sockets should be considered as class II if one or more of the following exists: mild periodontal or endodontic conditions, thin gingival phenotype, less than 2 mm of buccal bone thickness, less than 50% buccal dehiscence, and/or with or without some interproximal bone loss and/or mild apical pathology. Finally, class III sockets were considered to be those of teeth with severe periodontal or endoperio lesions, existing gingival recession greater than 3–4 mm and severe loss of buccal plate in terms of dehiscence. As with type II, only the presence of one of these findings is sufficient to label the socket as type III.

A logical sequence in assessing each single-rooted socket is to begin by assessing its gingival phenotype (thick vs. thin) and existing recessions to determine whether the esthetic outcome of an IIP would likely be favorable, stable long-term and pleasing to the patient. Rather than "biologic width," the term used with natural teeth, the vertical thickness of peri-implant supracrestal soft tissue (keratinized tissue height from bone crest to the coronal point of the junctional epithelium) has been termed the "supracrestal tissue attachment" (STA) [121]. The STA should be thicker by ≥ 1 mm than the biologic width around natural teeth [122], but if not, it will naturally thicken by crestal bone resorptive accommodation which is to be avoided. Ultimately, an adequately thick gingival phenotype (STA) will be at least as beneficial as

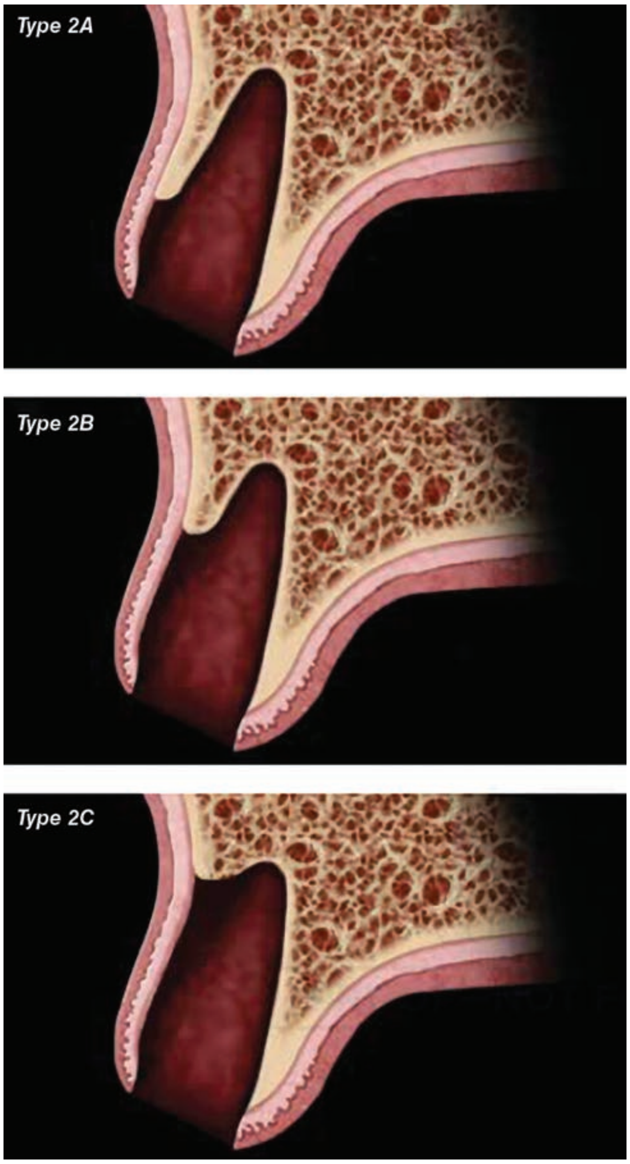


Figure 1.13 The subclassification of Elian's type II socket. *Source:* Elian et al. [119].

the post-treatment buccal bone thickness in maintaining successful long-term esthetics [123, 124].

Next, CBCTs should be used to determine the conditions of the socket hard tissue walls. As noted, the thickness and integrity of buccal bone socket wall needs assessment, as well as the integrity of the interproximal bone, which will be of prime importance in predicting the degree of papilla reformation that might be anticipated. The presence and extent of bone loss due to apical pathology also can be assessed in these radiographs to ensure sufficient healthy native bone (3–4 mm) remains apically to stabilize an IIP. As already stressed, implant positioning towards the palate will help to ensure that the future IIP will not be in contact with buccal bone, remembering that ideally a buccal gap of > 2 mm must be left between implant and inner surface of the buccal bone.

Systemic patient factors also need documentation as IIPs may not be appropriate for patients with chronic diseases such as diabetes or other conditions requiring regular use of medications that may affect wound healing. It also may be unwise to place IIPs in smokers for the same reason. IIPs also are inappropriate in patients with a history of severe periodontitis or current active periodontal disease because of the risk of wound infection and eventual peri-implantitis. It should also be noted that continuous craniofacial growth exists in mature adults, [125, 126] meaning that at patient recalls vigilance is needed to ensure that excessive occlusion or loss in interproximal contact of the implant haven't developed.

Accepted Ways of Minimizing Peri-Implant Crestal Bone Loss with Immediate Implant Placements

Considerable research efforts have been devoted to uncovering ways to minimize FAB thinning and vertical crestal bone resorption at sites that have been managed with IIPs. As already noted, proper 3D implant positioning and grafting of buccal bone gaps are musts as is subcrestal placement, particularly on the facial/buccal aspect. Some investigators [127] have suggested that additional graft should be used above the implant–abutment junction to provide further soft tissue support under the healing abutment or transitional crown margins ("dual zone grafting"). In any event, with careful planning and technique, it has been established that it is possible to achieve almost "zero bone loss" or even crestal bone gain with time in function [105], although as stated, modification of gingival phenotype (STA) may be needed. One group of investigators calculated that the threshold for gingival thickness that would limit crestal bone loss was almost 3 mm (i.e. 2.88 mm) [128].

The least invasive way to thicken a thin gingival phenotype over an implant is to place the implant subcrestal by at least 2 mm, as this will result in a similar increase in overlying soft tissue thickness during healing [107]. With IIPs, any thickening of the gingival phenotype achieved with subcrestal implant placement can be further enhanced by adding a subepithelial connective tissue graft or a soft tissue xenograft (e.g. Mucograft®, Geistlich Pharma AG, Basel, Switzerland) over the implant site for submerged healing or as a "poncho" over and secured by an added healing abutment for non-submerged healing [129]. Adding a subepithelial connective tissue graft to the IIP procedure ultimately will help to minimize loss in vertical height of the buccal bone [130]. The timing (before, during or after implant placement) of this soft tissue grafting can be left to the surgeon's preference.

Additional effective ways to minimize or prevent crestal bone loss with IIPs include using implants with a platform switch feature. Platform switching, as first defined by Lazzara [131] as connecting a prosthetic abutment smaller in diameter than its corresponding implant prosthetic table, creates a horizontal component to the surfaces available for STA (implant-related "biologic width") [132] accommodation or even overgrowth of bone, and as a result reduces the amount of crestal bone loss over the long term [133, 134]. Placing customized healing abutments or transitional crowns at the time of implant placement also helps to reduce post-extraction horizontal alveolar ridge shrinkage [37, 52, 135] by providing the bone stimulus of immediate non-occlusal loading [136], as well as maintaining the original (i.e. pre-extraction) soft tissue profiles.

Newer, unique implant designs such as the "Inverta" (Southern Implants, Irene, S Africa) [137, 138] also can be effective in reducing crestal bone loss by allowing larger coronal peri-implant gaps to be maintained for bone substitute grafting [139]. Their design is referred to as reverse tapered since they have a tapered apical segment to stabilize the implant but a cylindrical coronal segment of a narrower diameter to leave significant gaps for grafting (see Chapter 13).

Conclusions

Immediate implant placement is becoming more and more common due to patient demand. However, it is not a simple approach and requires considerable experience and understanding to use effectively, especially in the maxillary esthetic zone. Proper patient and site selection are essential to produce favorable and stable long-term outcomes esthetically. Even if the initial outcome appears favorable, longer-term esthetic disasters are almost inevitable if small details of technique are ignored.

Key Points

1) Placement of immediate implants (IIPs) in anterior and premolar sockets ("immediacy") has become a patient expectation.
2) While IIP management does appeal to patients and has biologic advantages, such as minimizing the typical alveolar ridge shrinkage seen following tooth extraction, it is an approach requiring a clear understanding of the inherent risks and their prevention.
3) Pretreatment CBCT assessment of the socket condition is essential to be able to decide whether IIP is appropriate.
4) If the site has a thin gingival phenotype, based on visibility through the gingival tissues of an underlying periodontal probe placed in the facial gingival crevice (i.e. visible, thin; not visible, thick), provisions should be made to thicken it to minimize crestal bone loss and prevent associated gingival recession.
5) Very careful attention must be made to choosing the correct implant diameter to leave a large buccal gap and avoid compromising implant-to-adjacent tooth or implant-to-implant interproximal bone and subsequent papilla reformation.
6) Implants should be inserted subcrestal by up to 2 mm so as to be at a level where the buccal plate is ≥ 1.5 mm in thickness, to avoid rapid loss of thin crestal bone.
7) Implant surface-to-bone buccal gaps must be hard tissue grafted to allow for a thick buccal plate of bone to develop and be maintained.
8) Ideally, customized healing abutments or temporary crowns supporting the original soft tissue profiles and sheltering the grafted gaps should be inserted at the time of implant placement.

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